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Title:	Mechanical Properties of an Irradiated Inconel 718 Beam Window
Author(s):	Saleh, Tarik A. Bach, Hong Maloy, Stuart A. Romero, Tobias J. Anderoglu, Osman
Intended for:	Report

Mechanical Properties of an Irradiated Inconel 718 Beam Window

Tarik A. Saleh[1],

Hong Bach[2], Stuart A. Maloy[1], Tobias J. Romero[2],

Osman Anderoglu[1], Bulent H. Sencer[3]

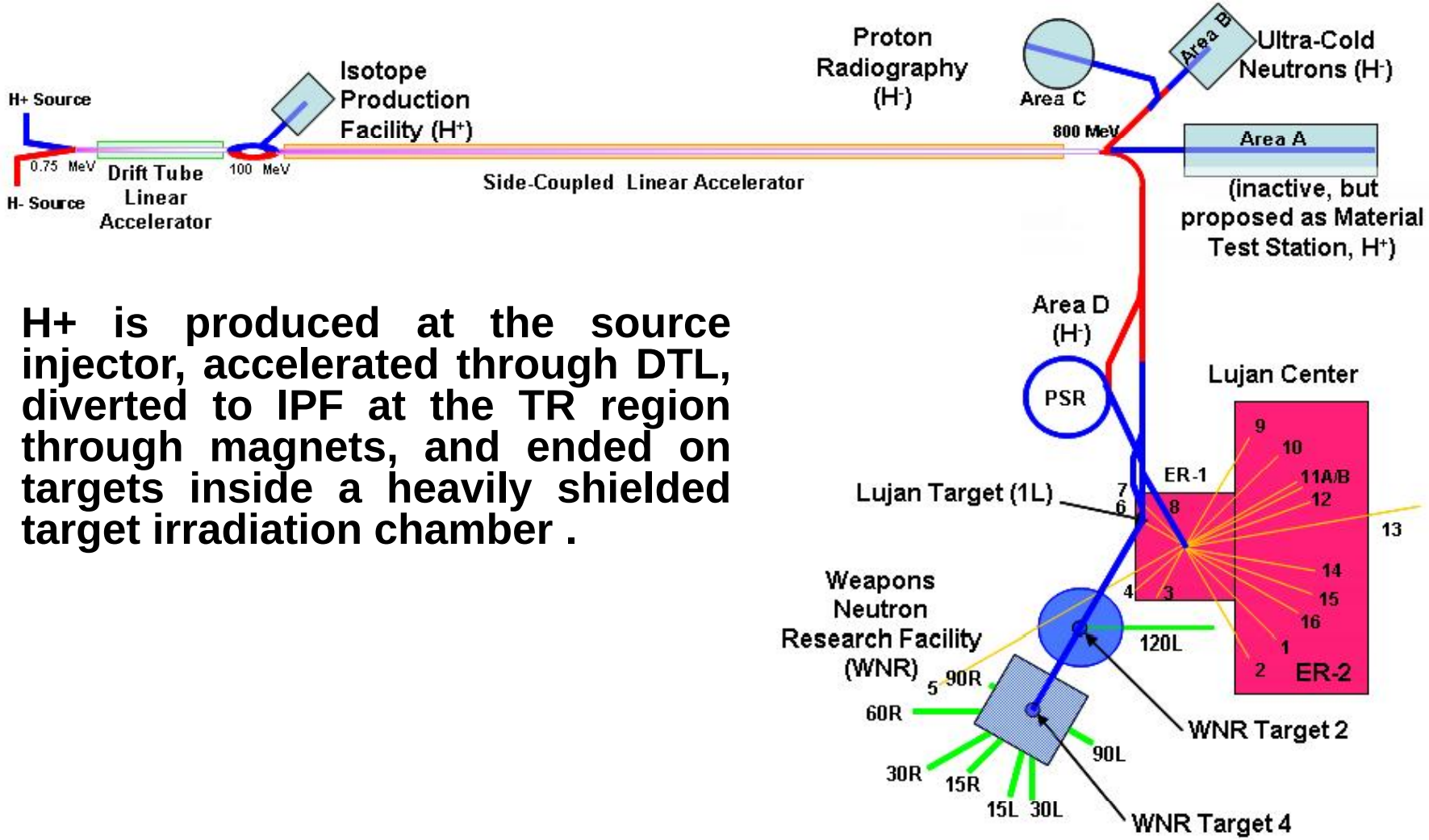
1. Materials Science and Technology Division -Los Alamos National Laboratory

2. Chemistry Division -Los Alamos National Laboratory

3. Idaho National Laboratory

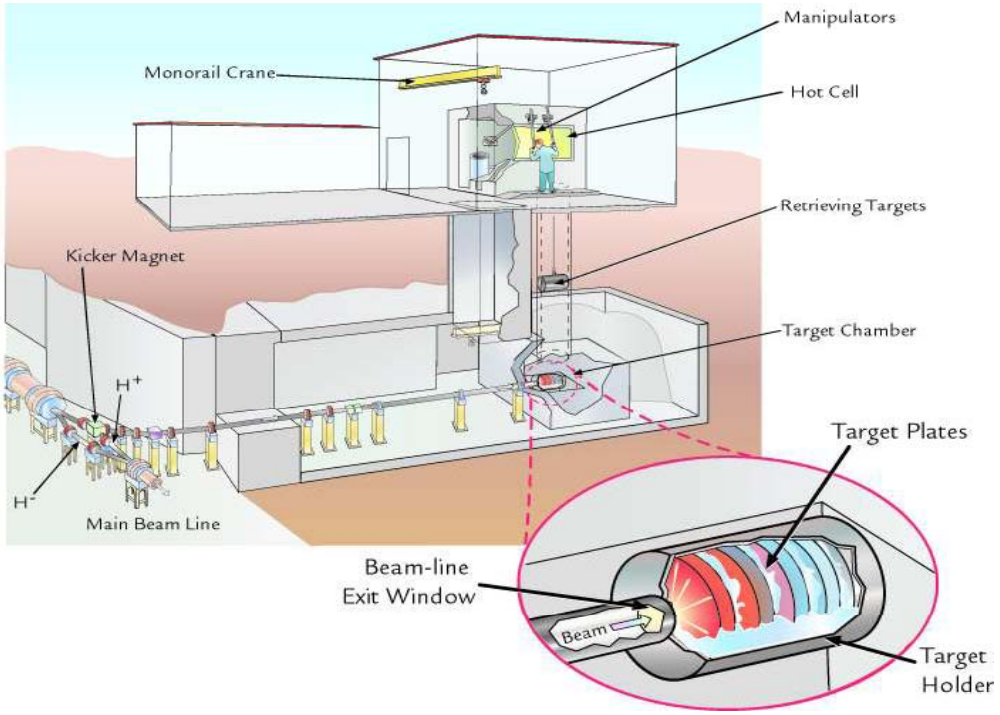
LA-UR 12-20674

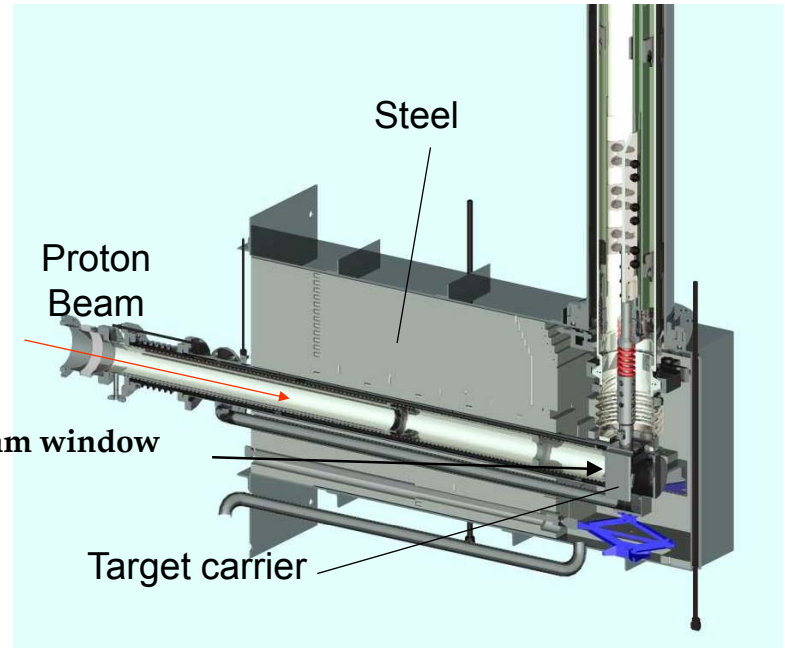
Isotope Production Facility - LANSCE



H+ is produced at the source injector, accelerated through DTL, diverted to IPF at the TR region through magnets, and ended on targets inside a heavily shielded target irradiation chamber .

Isotope Production Facility and Beam Window



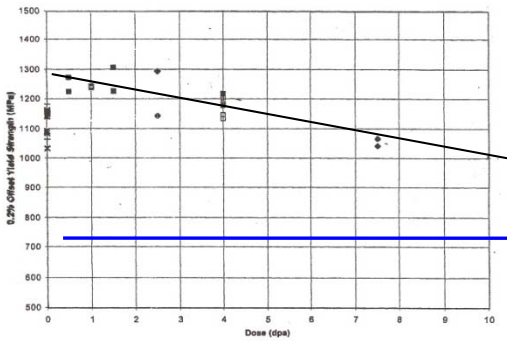


The proton beam is delivered via a vacuum beam pipe. Inconel beam window isolates the beam pipe (under vacuum) and the target irradiation chamber (15 psig of cooling water).

Irradiation Damage and Replacement

- Beam transmission through the window incurs heating causing thermal stress.
- Beam irradiates the window causing mechanical properties to change and to become more ductile.
- Beam window design criteria is 20 dpa (displacement per atom). Beam window reached the end of its life.
- Estimate dose rate is 100 R/hr at contact without shielding and highly contaminated.
- We replaced window in March 2010, stored at Area A and shipped to CMR in November 2010.

718 Yield



Dose, dpa

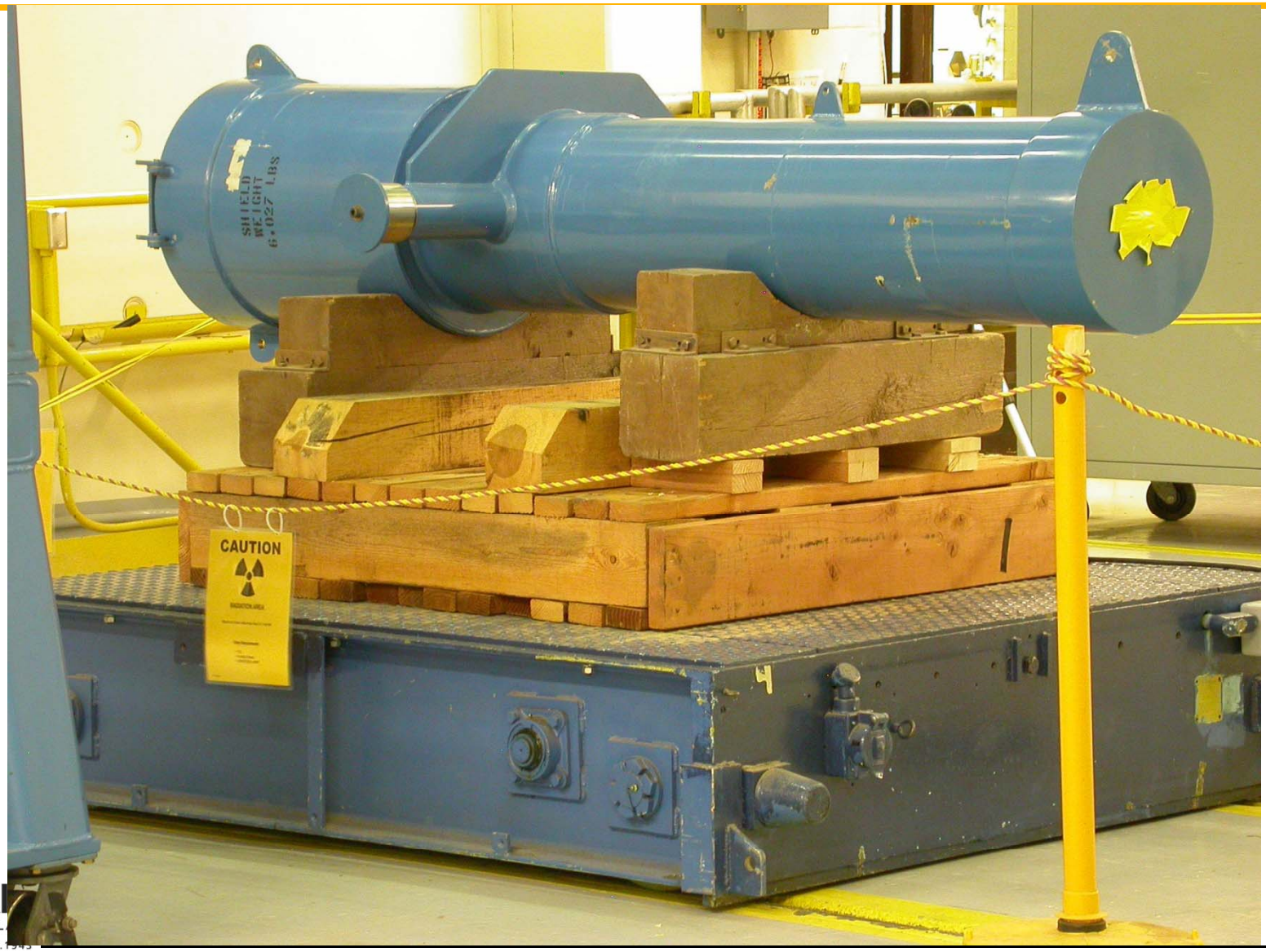
Calculated Von Mises stress under pressure and thermal load at the center of the target is ~ 510 MPa. Window will fail when Von Mises stress > the yield strength

15 **18** 20

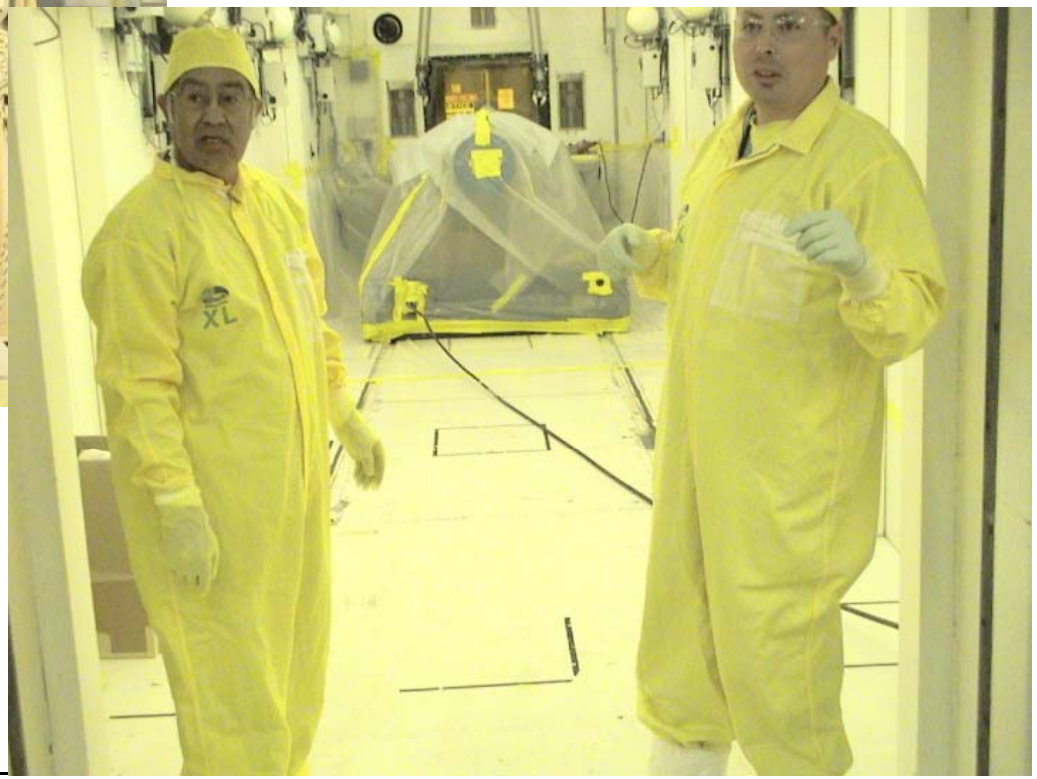
End of run cycle 2009

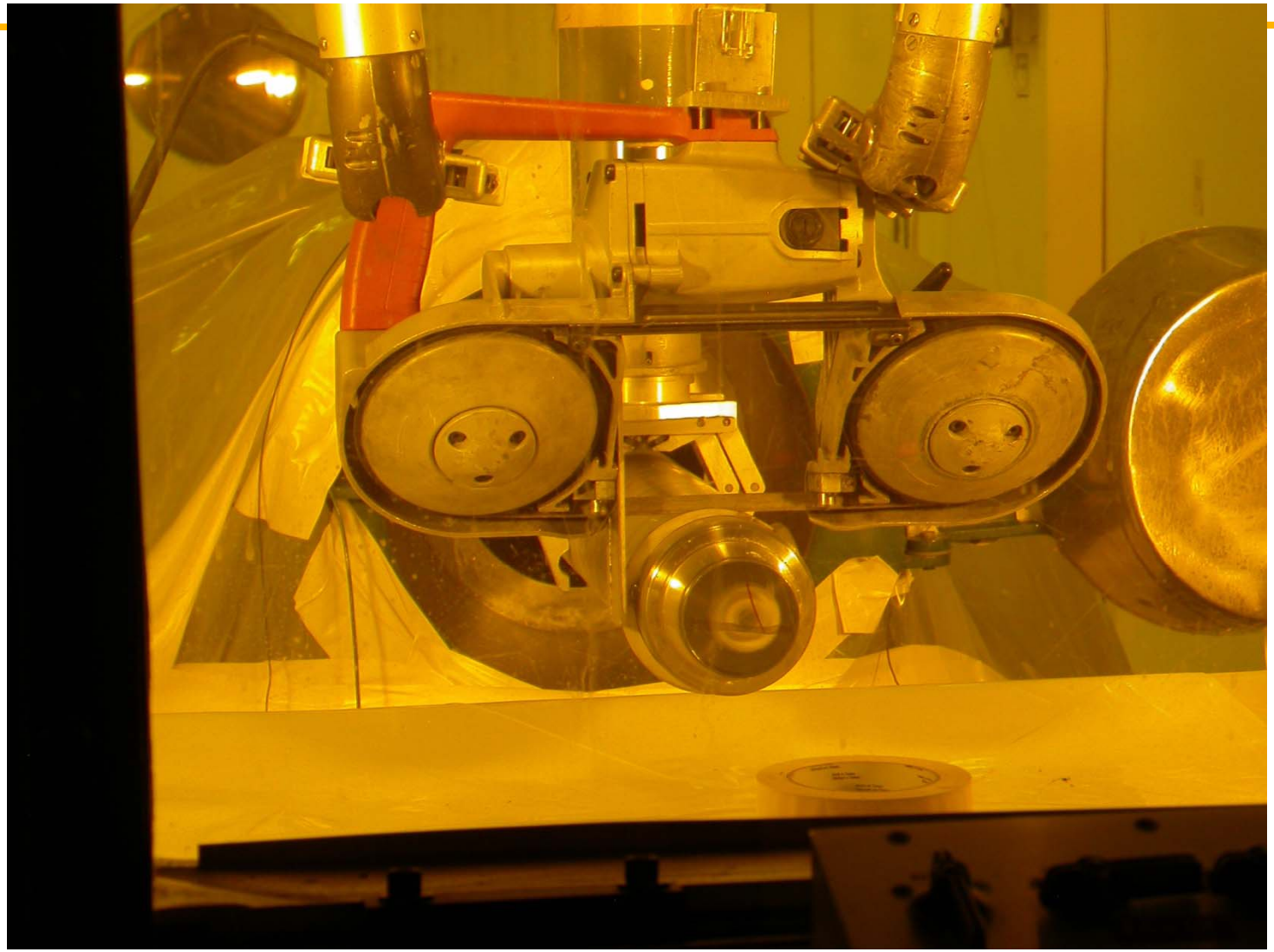
The Reality of High Rad Testing

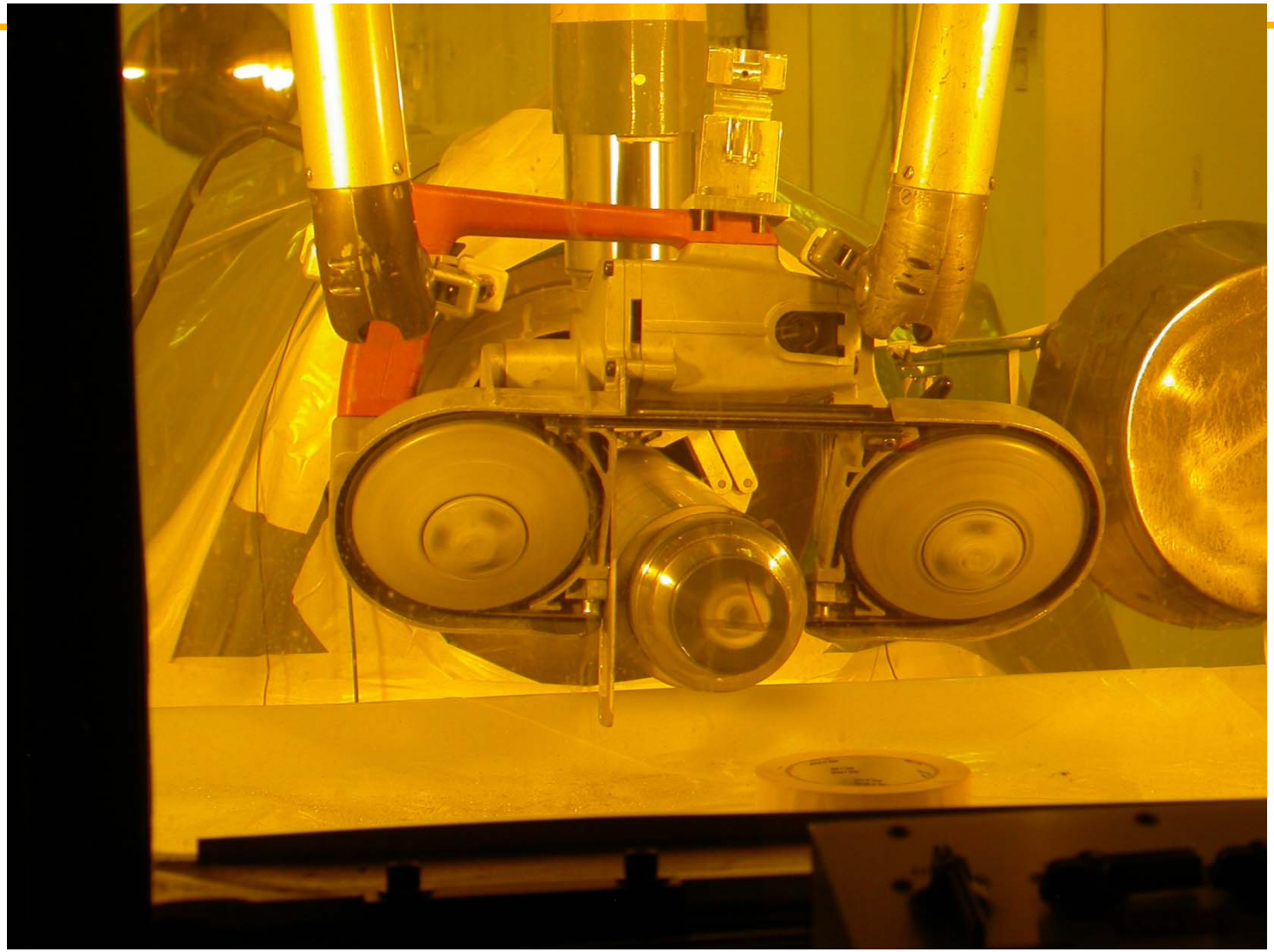
At CMR

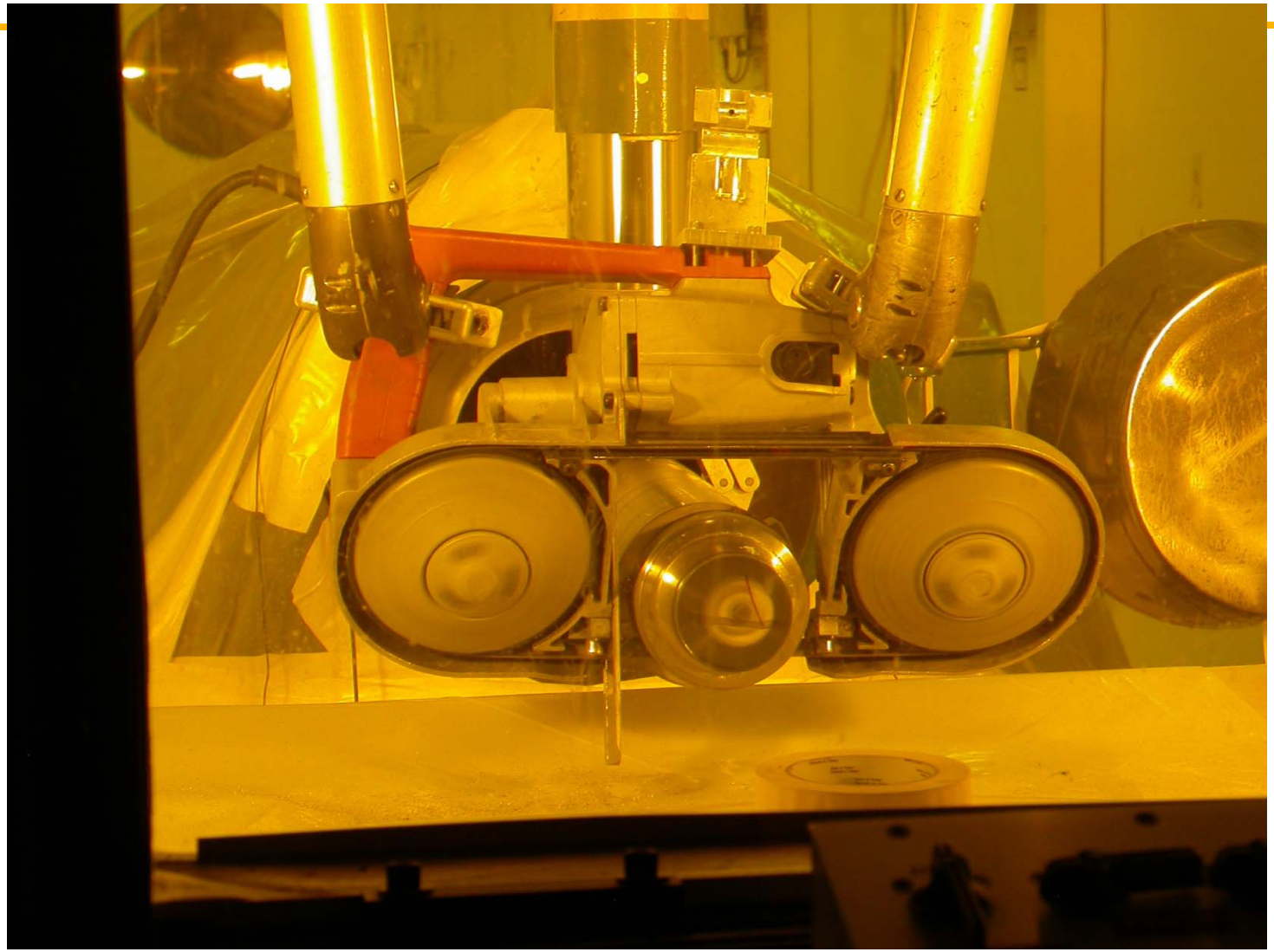


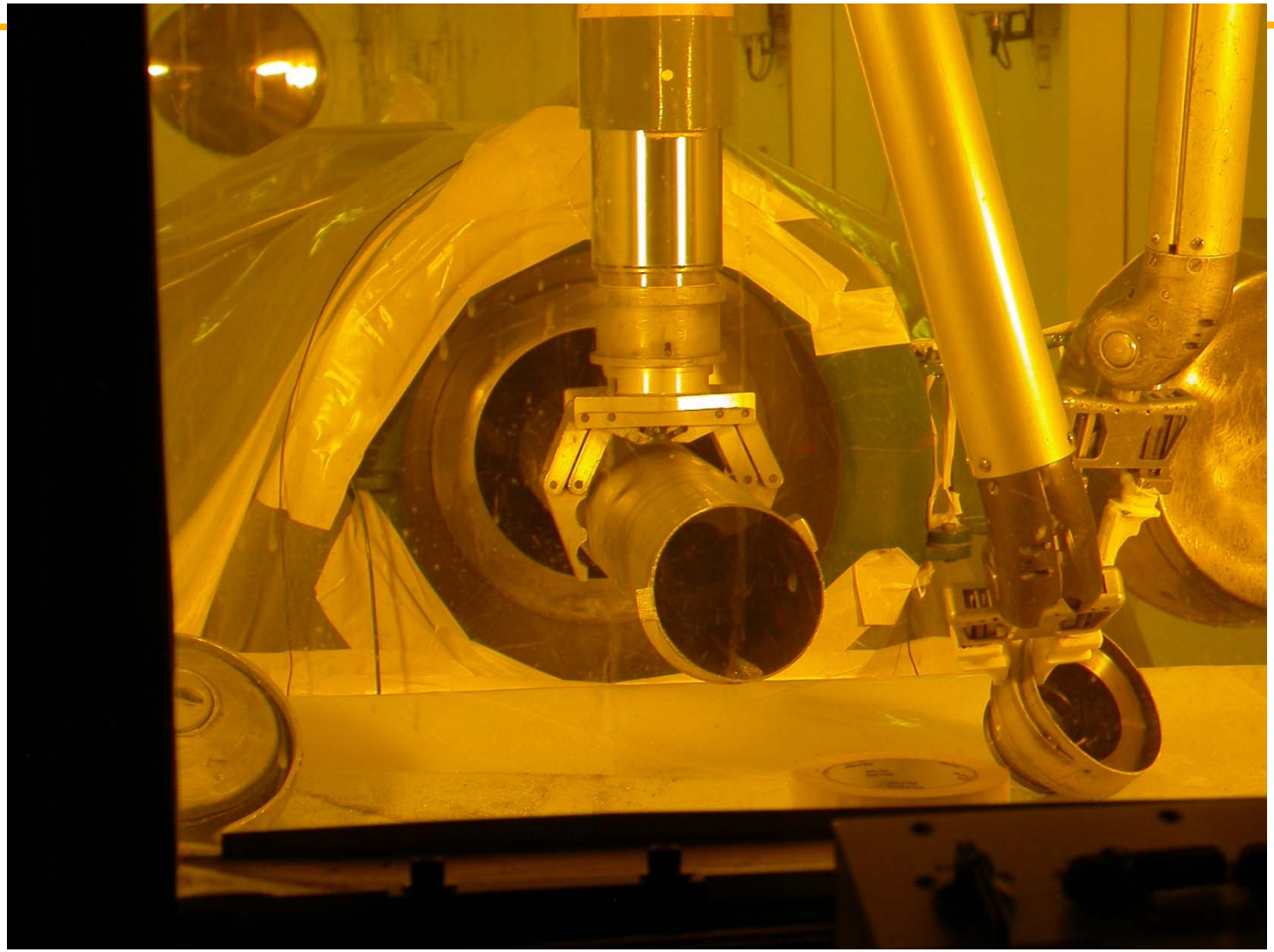
Into the Hot Cell Corridor



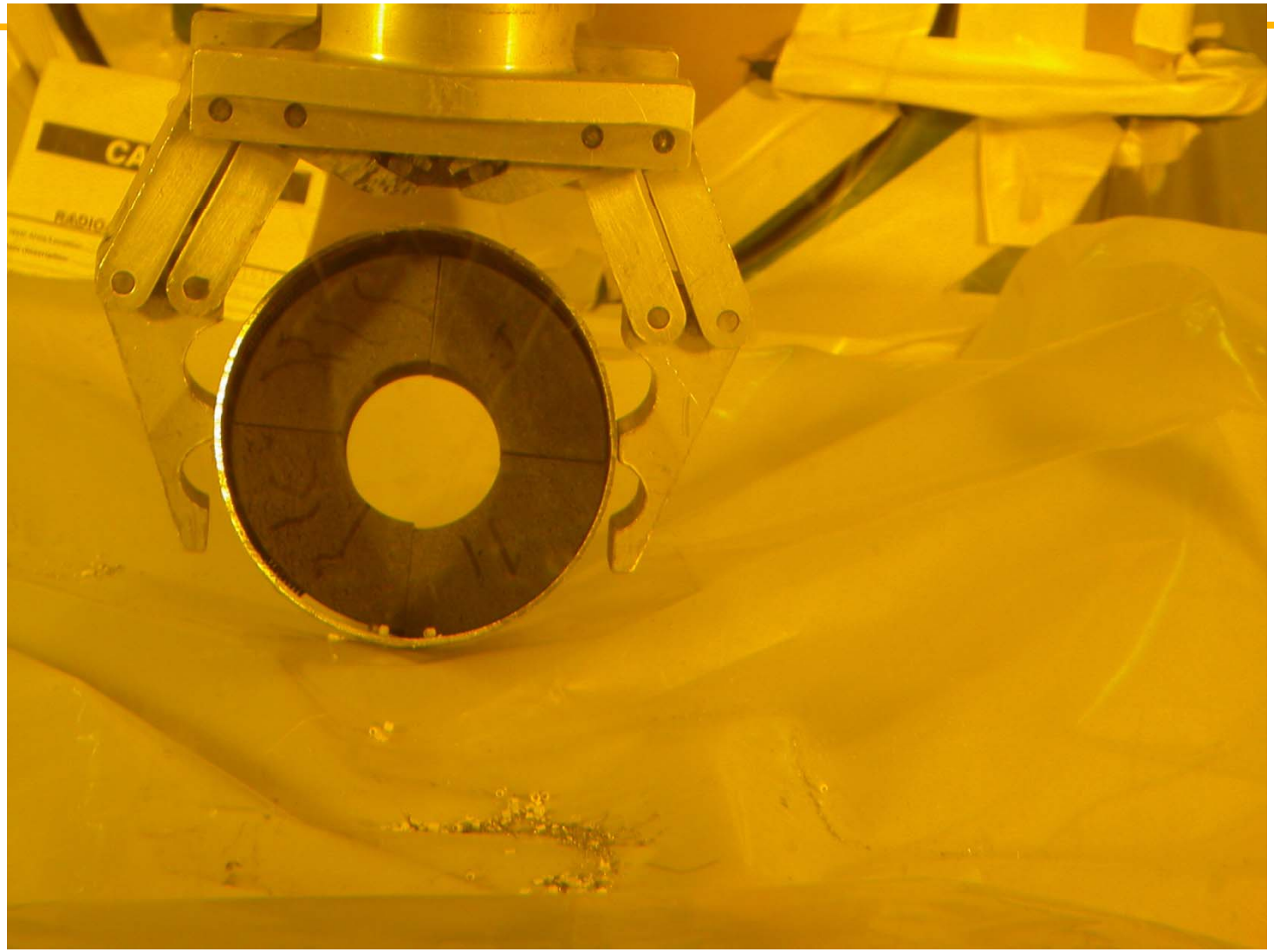






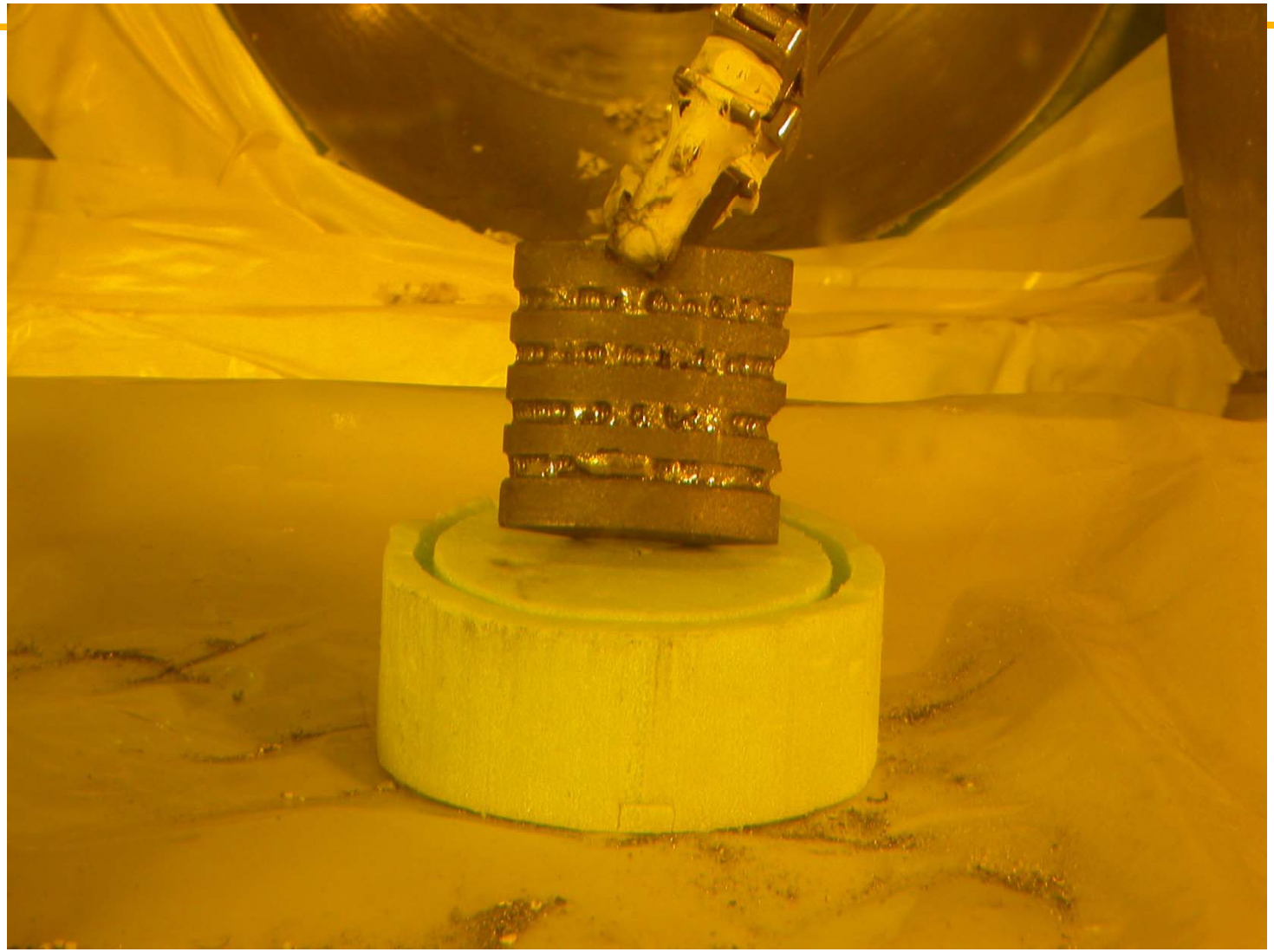


Graphite Colimator



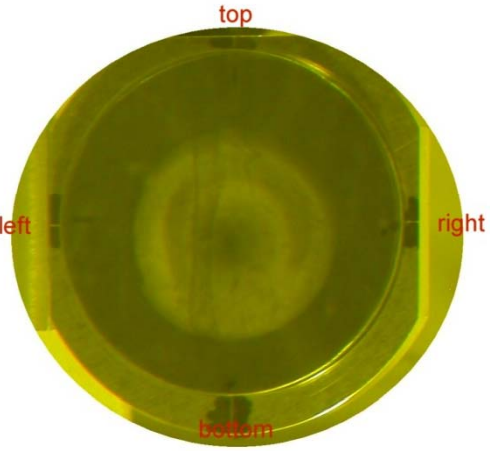
Retaining Springs not Intact

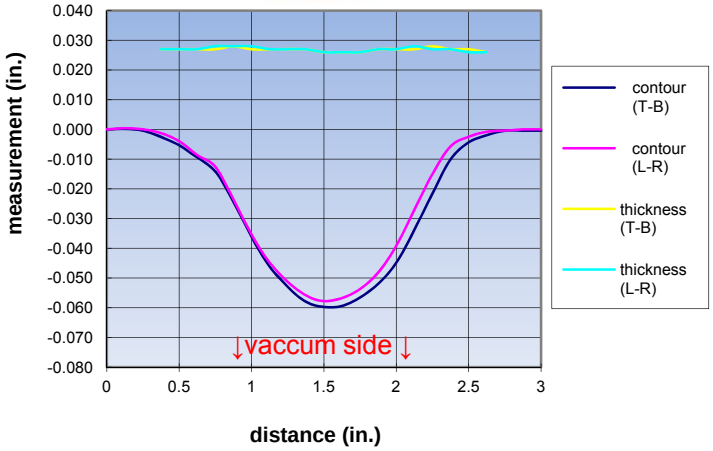
Melted Haynes 25 Spring, 50+R/hr , ~1350C Melt



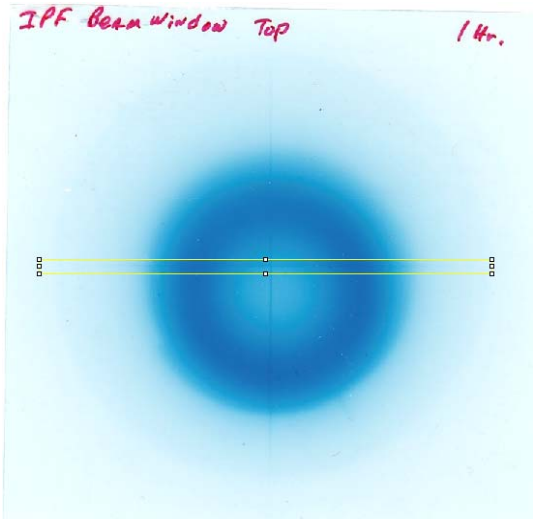
Beam Window Surface

Beam Window Bulging and Beam Profile Measurements

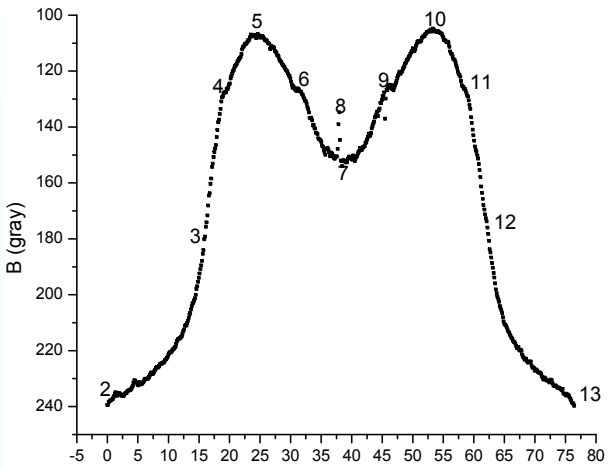


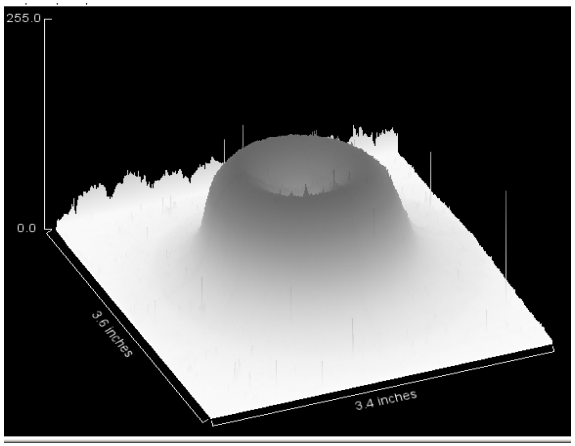


Beam window was bulged 1.5mm into the vacuum side.



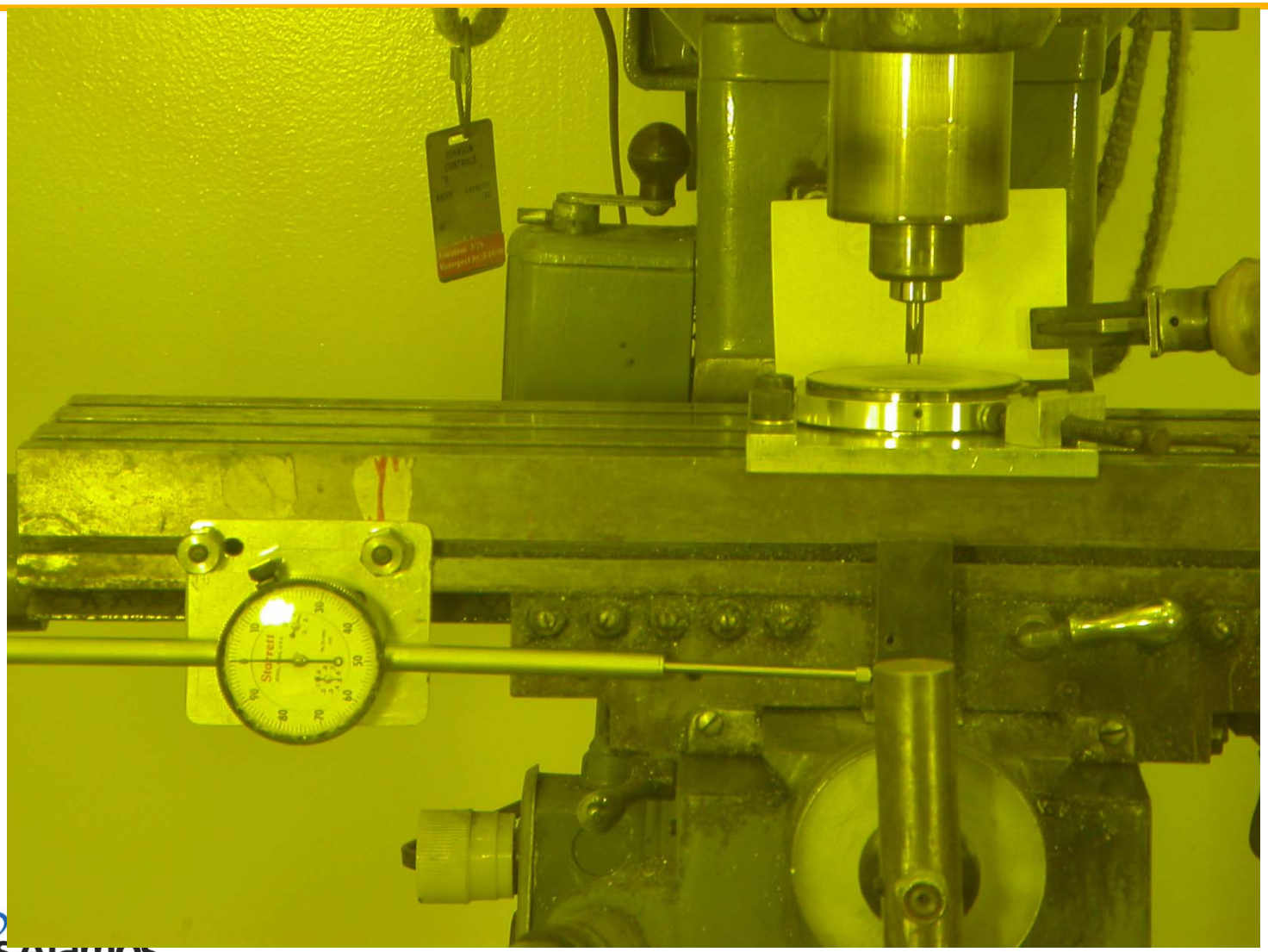
GAFCHROMIC HD-810 dosimetry film was used to measure the absorbed dose of high energy photons from the activated beam window.



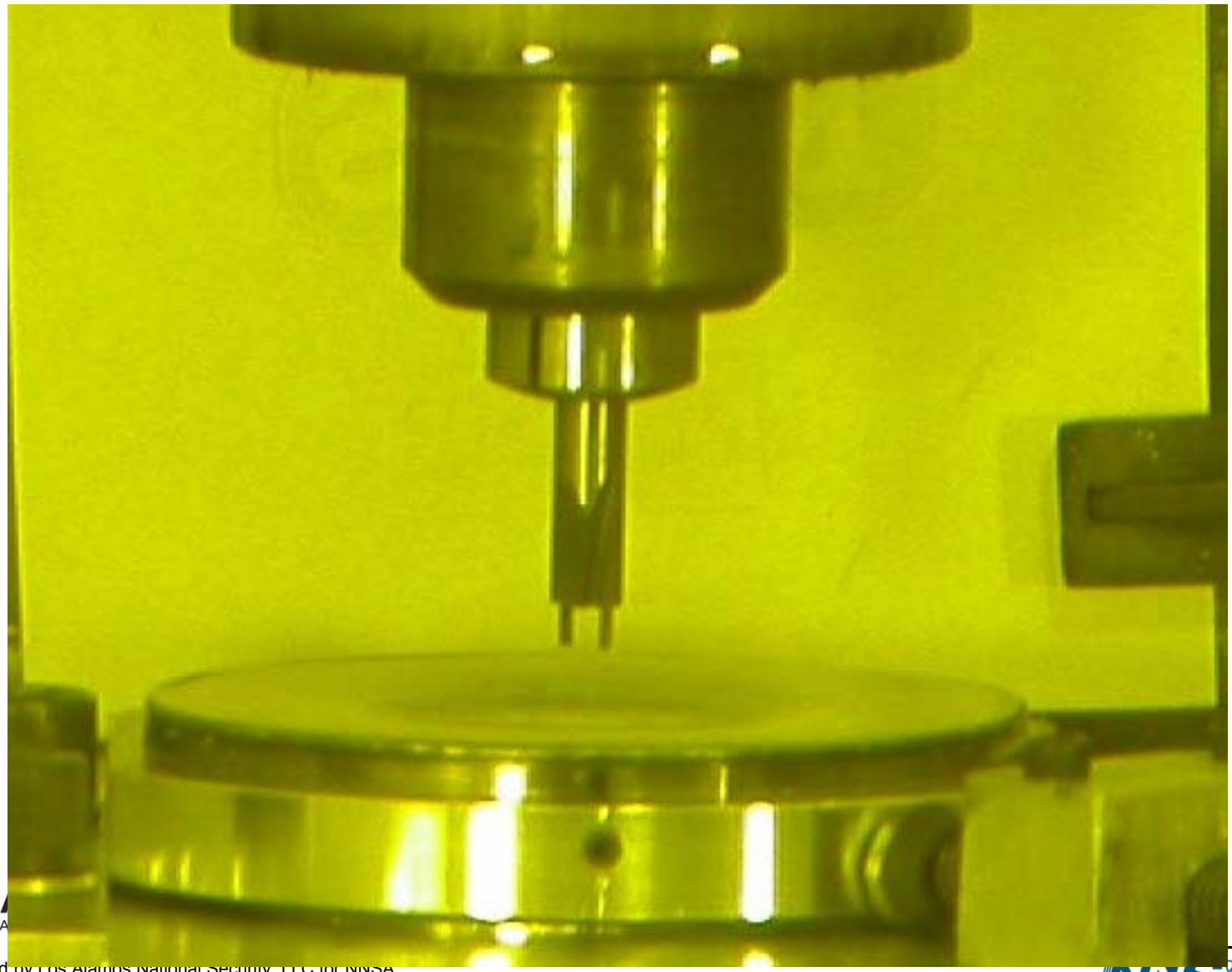


Rastered beam profile shows a Gaussian distribution and the highest dose region corresponds to the darkest blue region on the Gafchromic film.

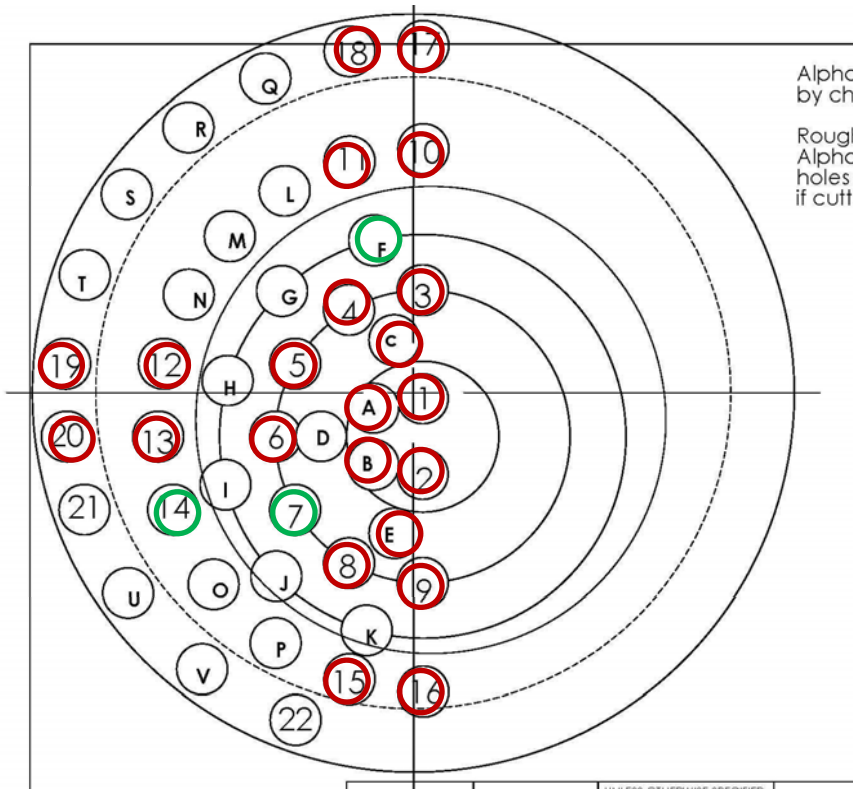
Machining Samples



Trepan tool



Cutting and Shear Punch Testing Plan



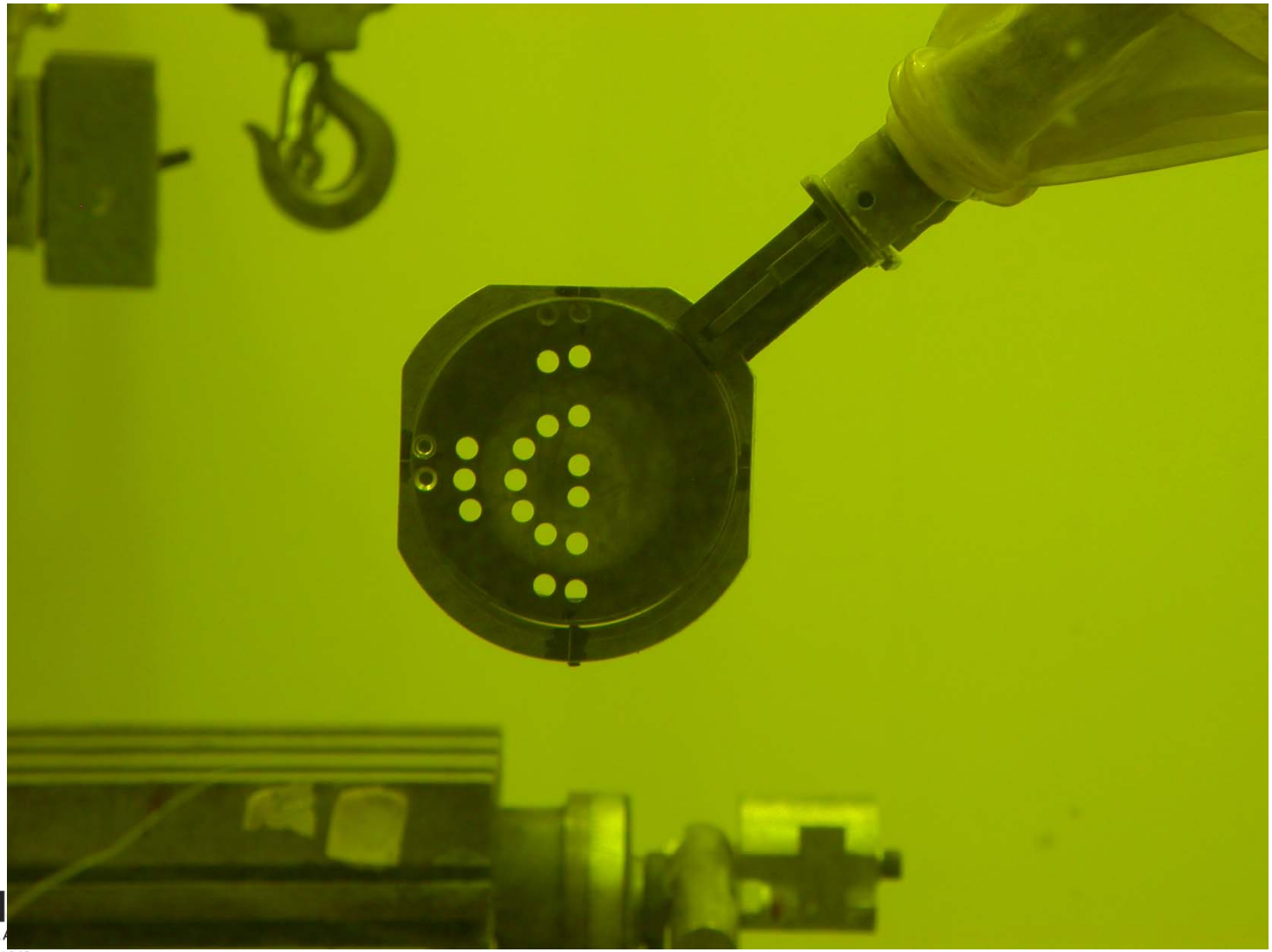
Samples Tested

Samples Cut but Untested

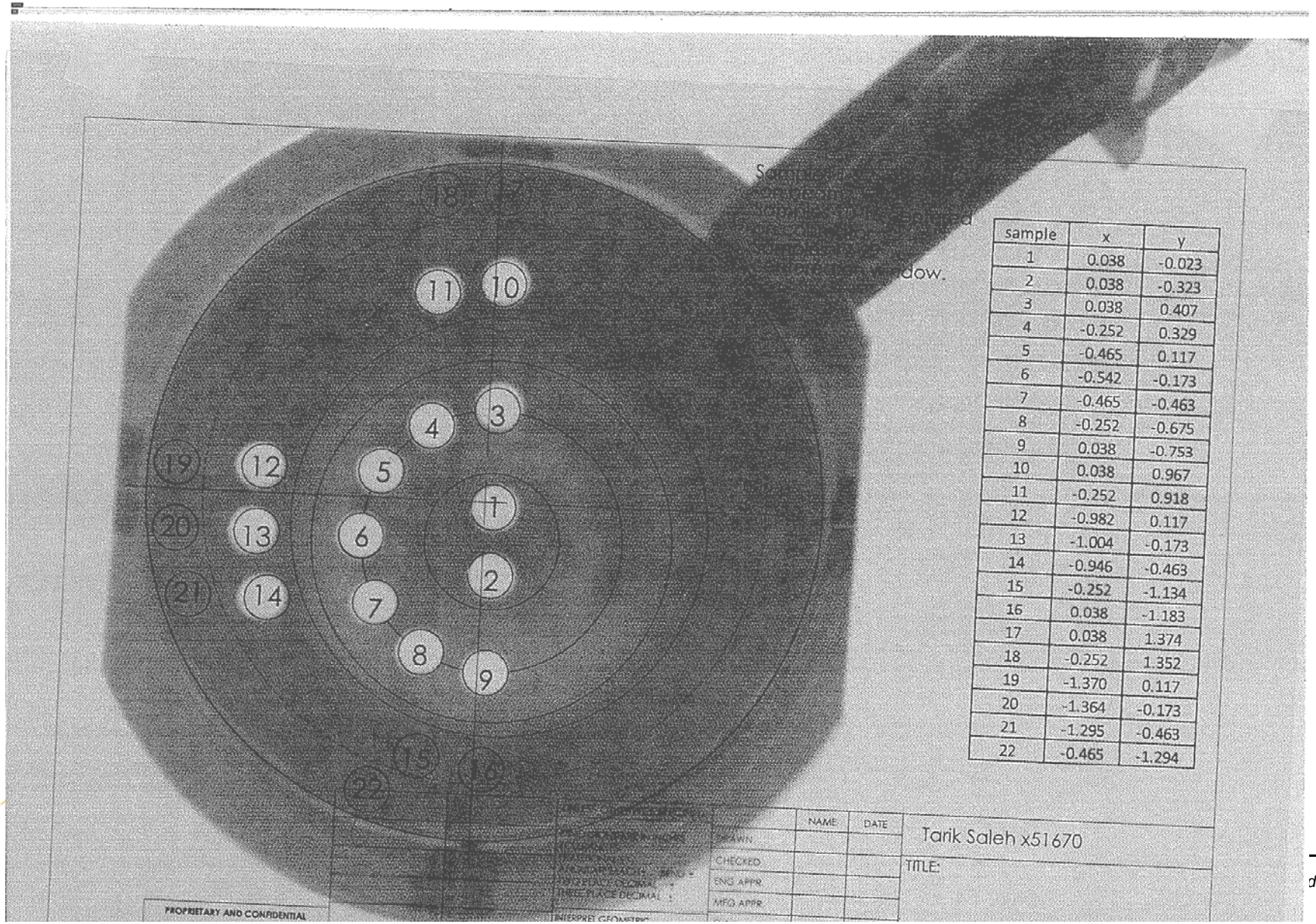
Black Circles were not cut

- Beam profile was superimposed on the window to determine the cutting plan as a function of radiation dose (dpa).
- 3-mm OD samples were cut with a Mill machine. A total of 3 cutting bits were spent to cut out 20 numerical samples (1-20) and 5 alphabetical samples (A, B, C, E, and F).
- Cut-out samples were polished and thinned from on both sides to 0.254 mm thickness.
- The shear punch testing for the following samples were completed as a function of radiation dose (dpa):
  - 2 controls samples of unirradiated Inconnel 718
  - 1-6, 8, 9, 10-13, 15-16, 17-18, 19-20, A-C, and E

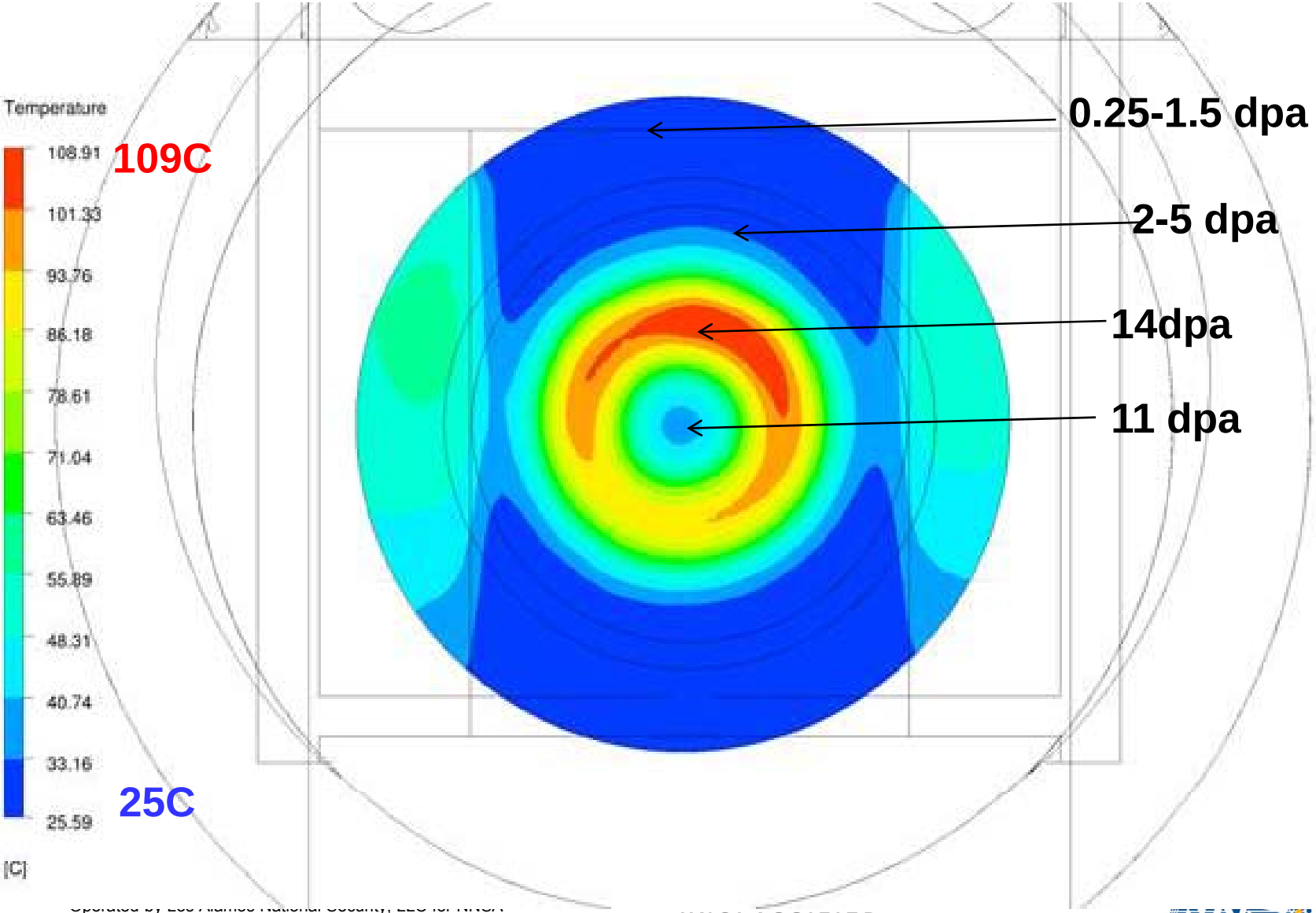
Machined Window



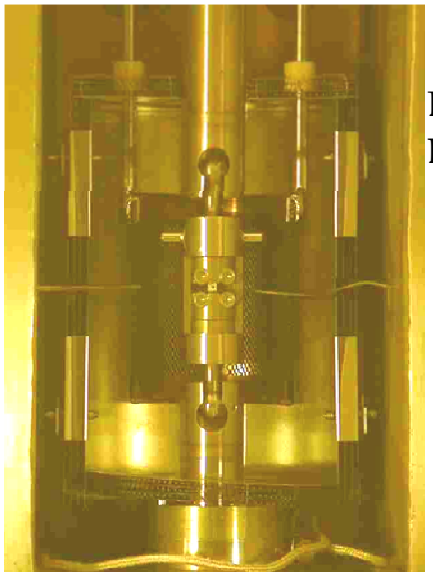
Overlay


18
17
11
10
4
3
19
12
5
1
20
13
6
2
21
14
7
8
9
15
16
22
dow.
sample x y
1 0.038 -0.023
2 0.038 -0.323
3 0.038 0.407
4 -0.252 0.329
5 -0.465 0.117
6 -0.542 -0.173
7 -0.465 -0.463
8 -0.252 -0.675
9 0.038 -0.753
10 0.038 0.967
11 -0.252 0.918
12 -0.982 0.117
13 -1.004 -0.173
14 -0.946 -0.463
15 -0.252 -1.134
16 0.038 -1.183
17 0.038 1.374
18 -0.252 1.352
19 -1.370 0.117
20 -1.364 -0.173
21 -1.295 -0.463
22 -0.465 -1.294
NAME
DATE
DRAWN
CHECKED
ENG APPR
MFG APPR
Tarik Saleh x51670
TITLE:
PROPRIETARY AND CONFIDENTIAL

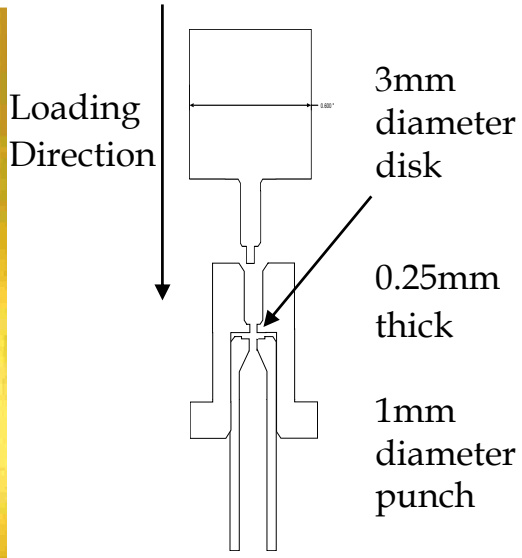
Temperature and Dose Map

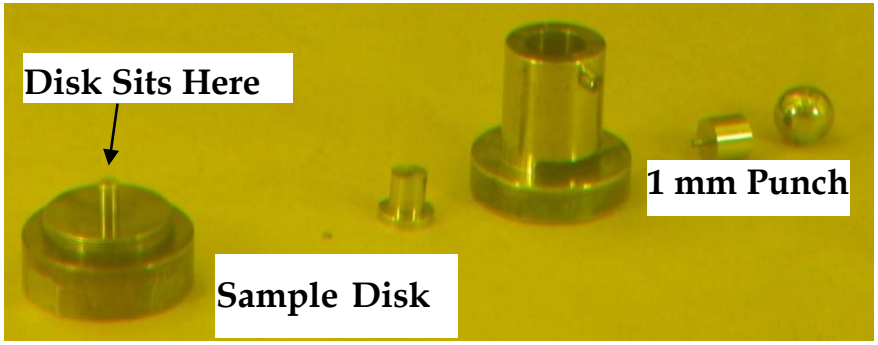


Shear Punch Testing Equipment at CMR Hot Cell



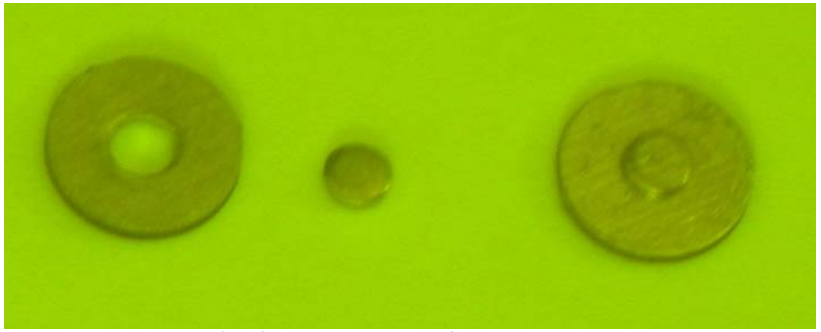
Shear Punch Set-up





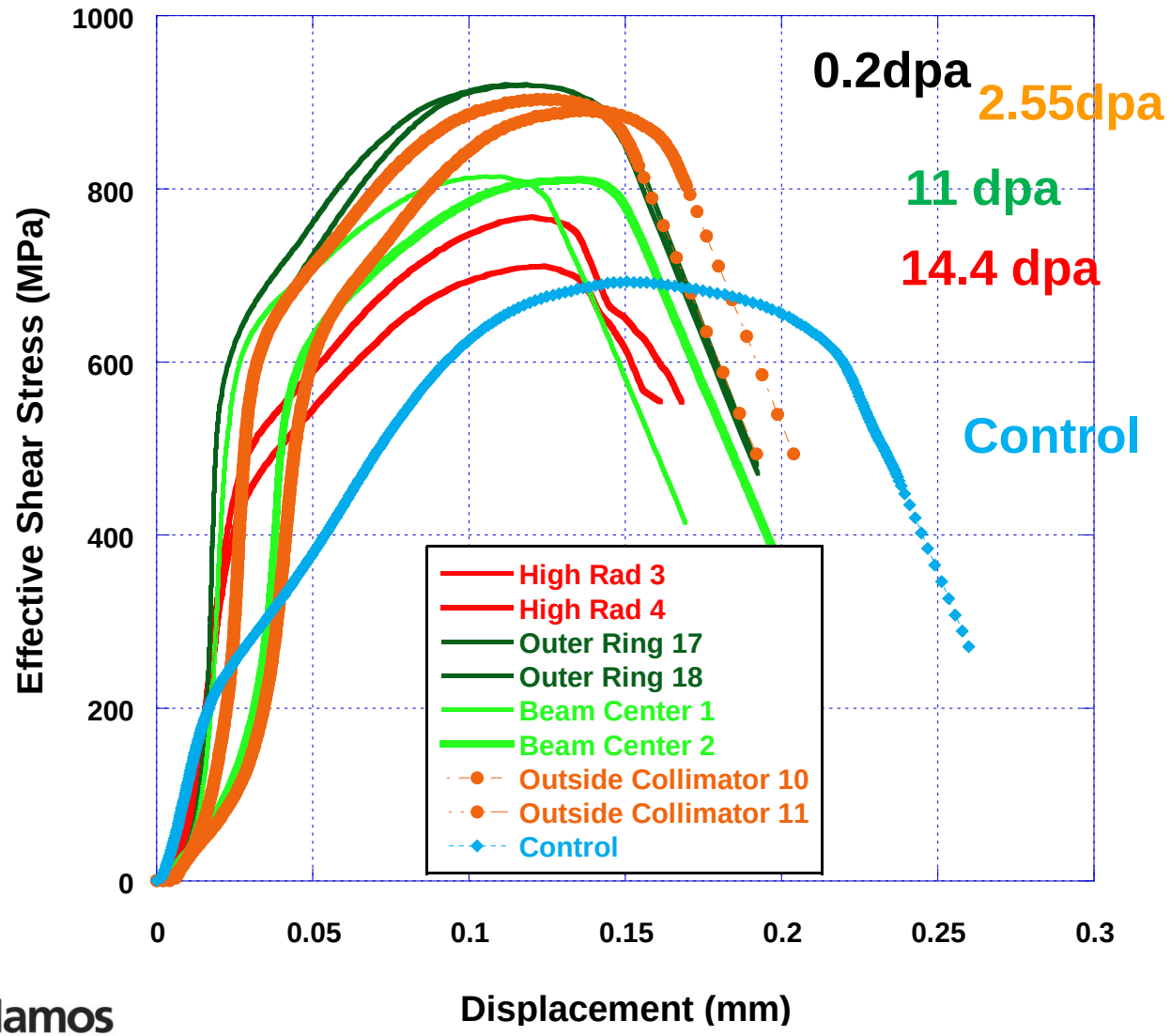
- Performed 25 shear punch tests on 3 mm diameter specimens.
- Tested at initial strain rate of 5 x 10-4/s.
- Tested at in ultra high purity argon.

Loading sequence

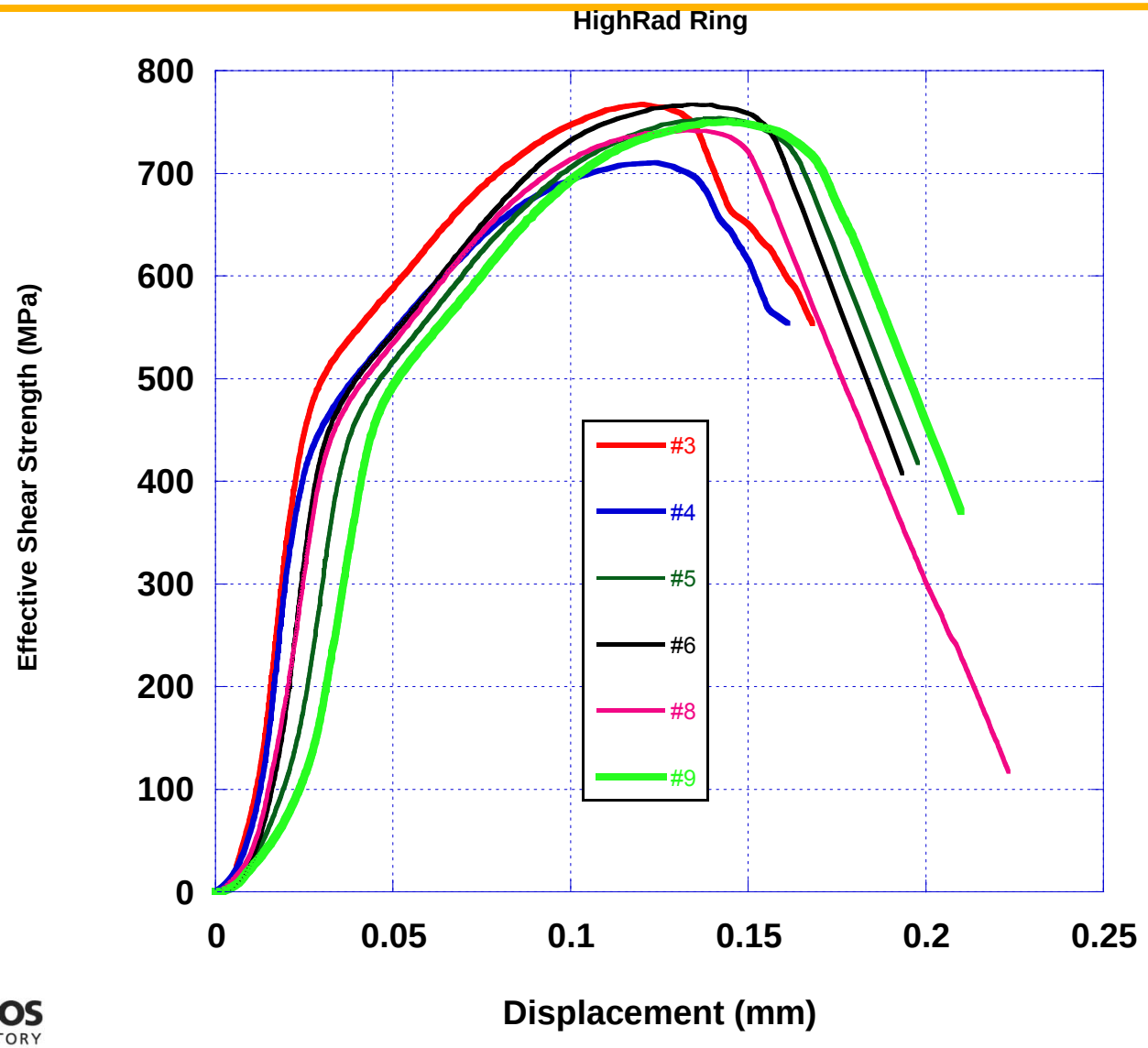


Typical shear punch specimen

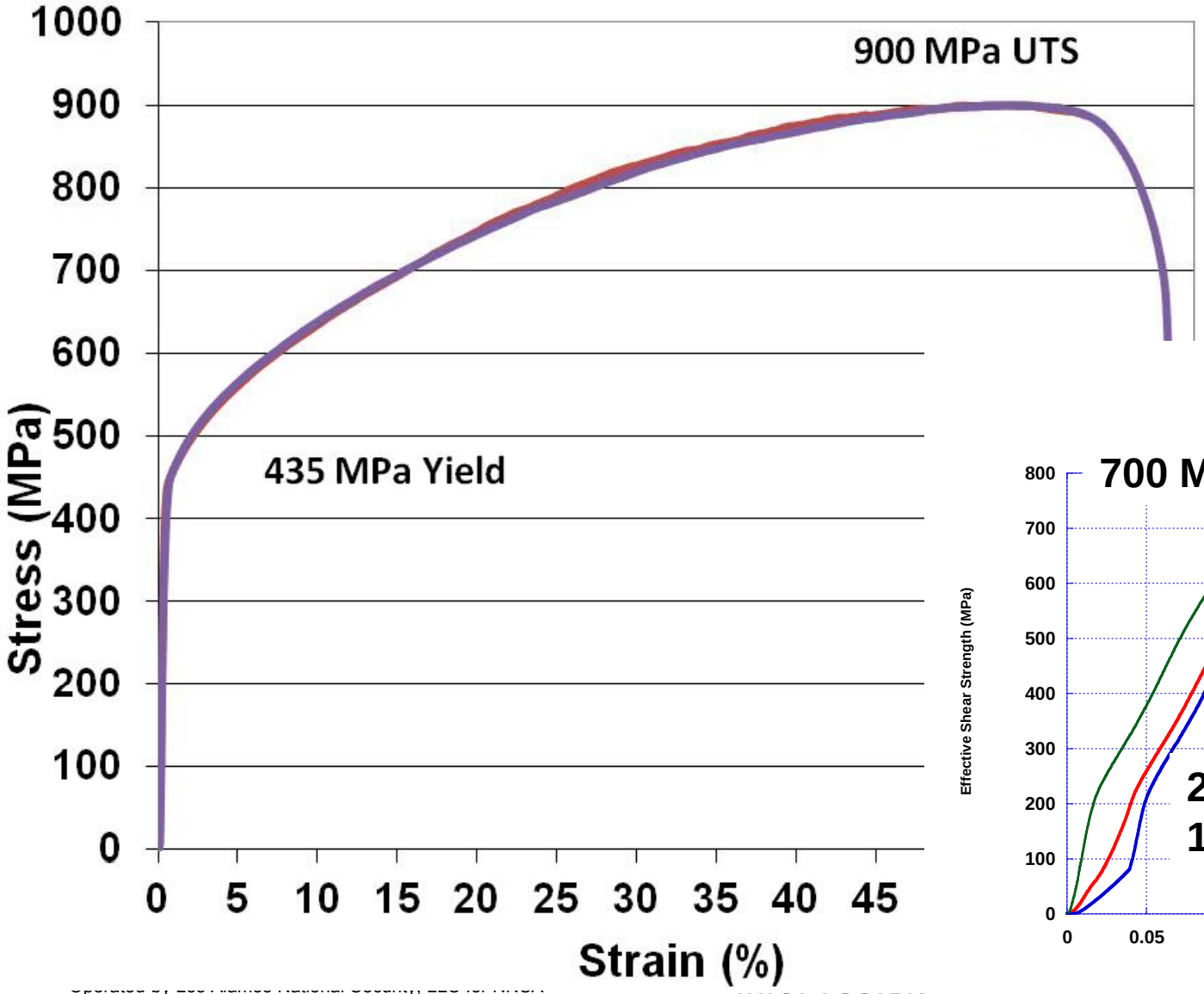
Shear Punch, Outer to Inner



14 dpa ring

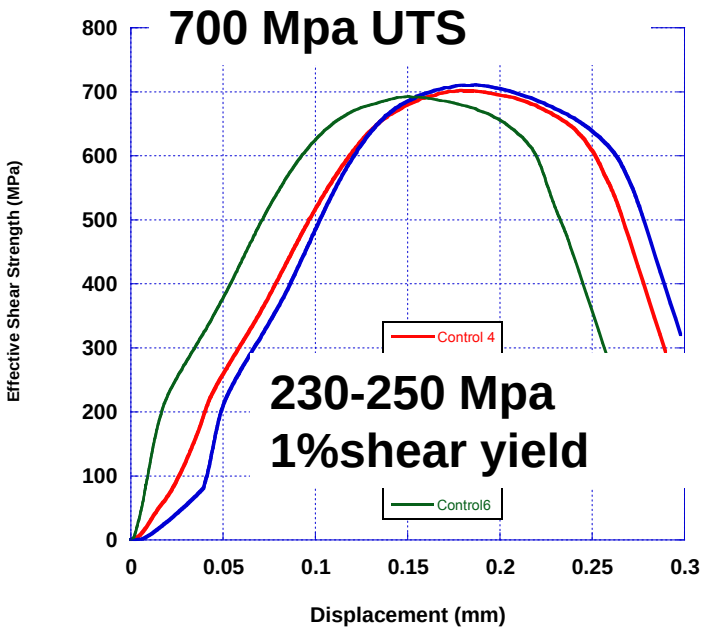

HighRad Ring
Effective Shear Strength (MPa)
800
700
600
500
400
300
200
100
0
0
0.05
0.1
0.15
0.2
0.25
Displacement (mm)
#3
#4
#5
#6
#8
#9

Control Material Tensile Tests vs Shear Punch

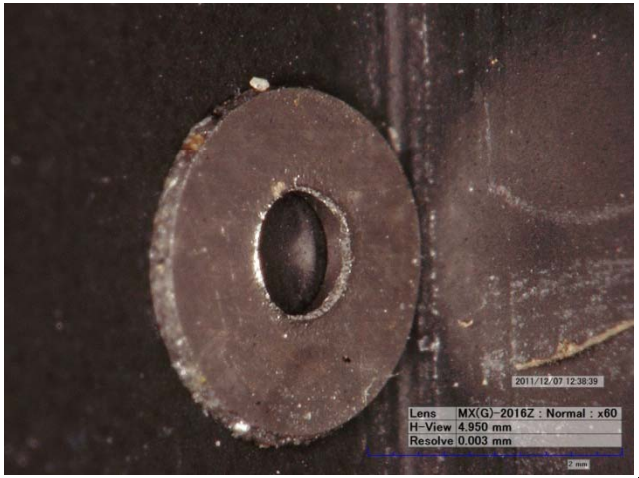


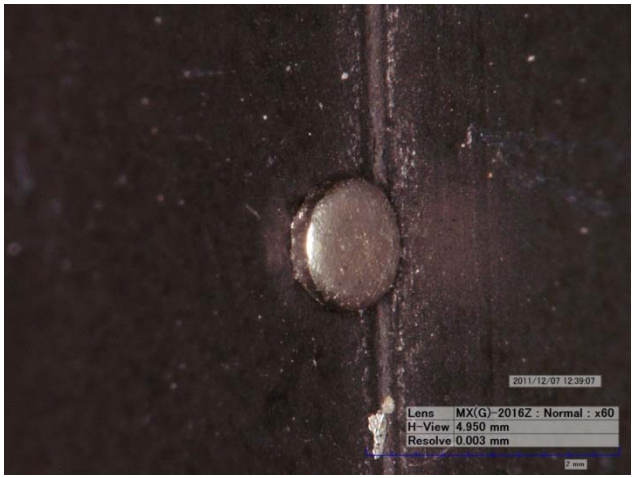
- UTS correlation - 1.28
- Yield Correlation- 1.77
- Lit values 1.4, 1.73

Toloczko&Kurtz

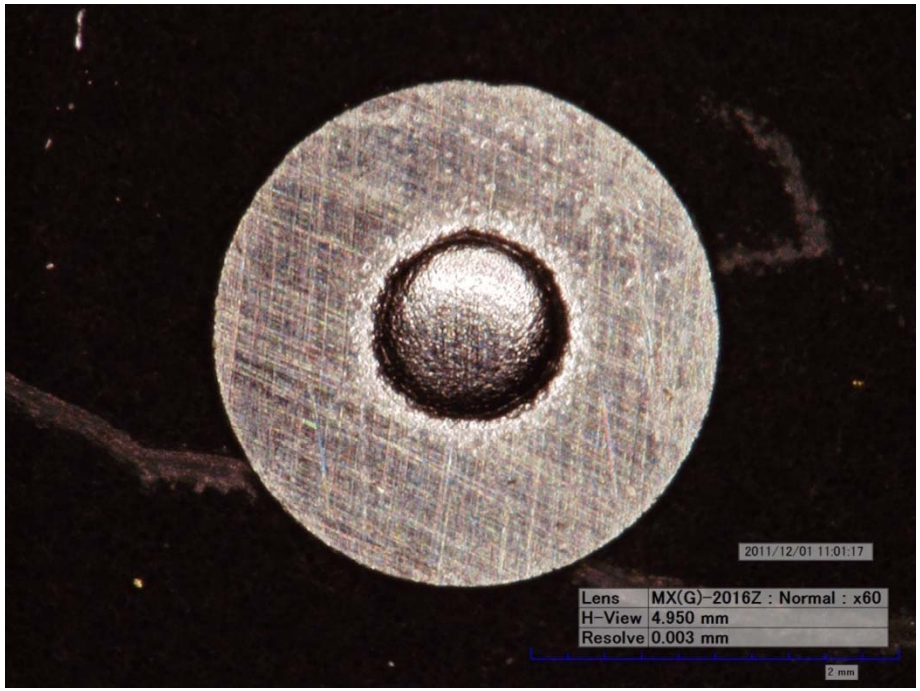


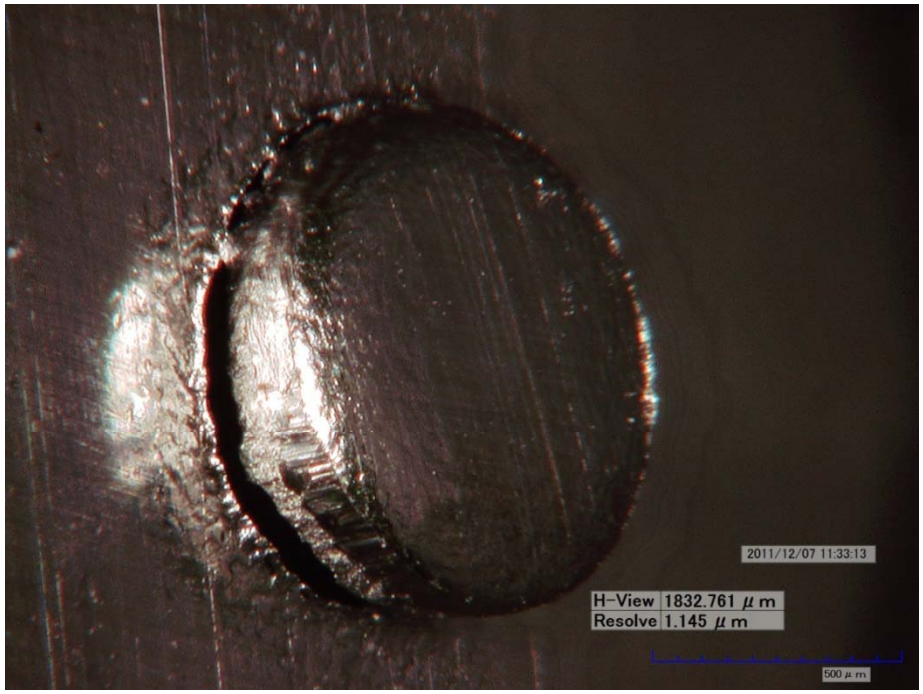
Optical Images of Control Sample #1 (Unirradiated)



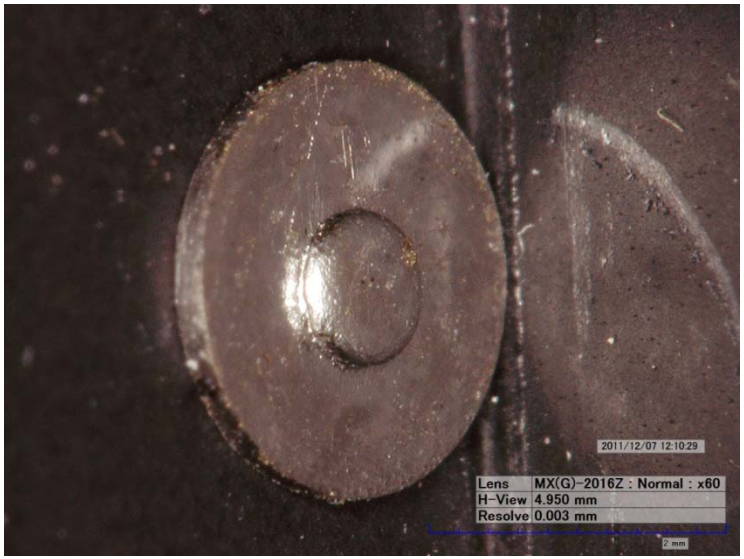


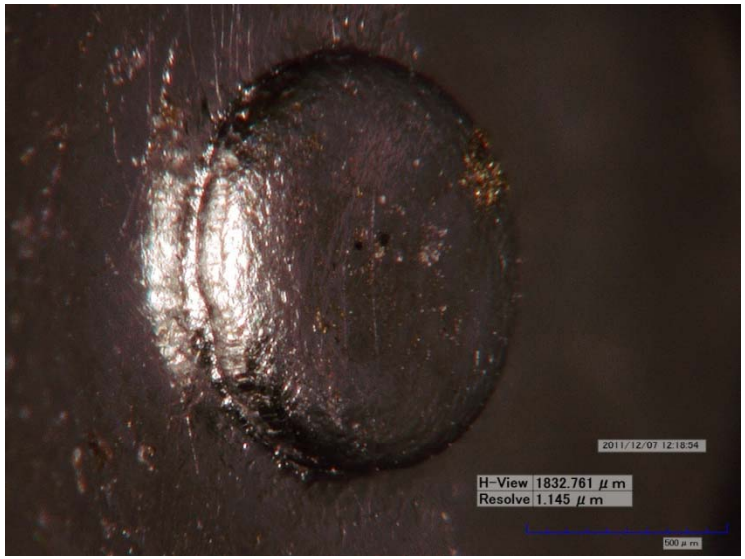
Optical Images of Control Sample #6 (Unirradiated)



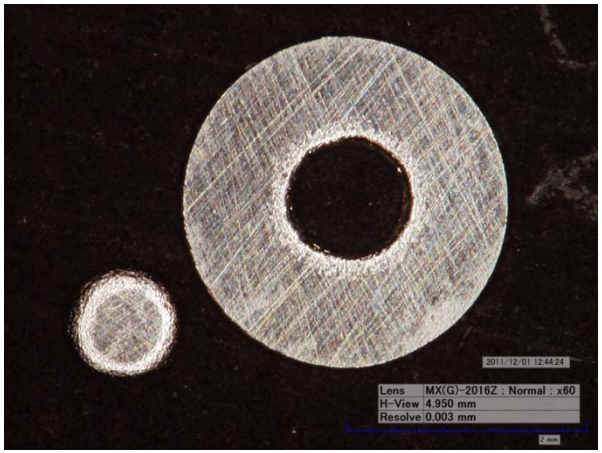


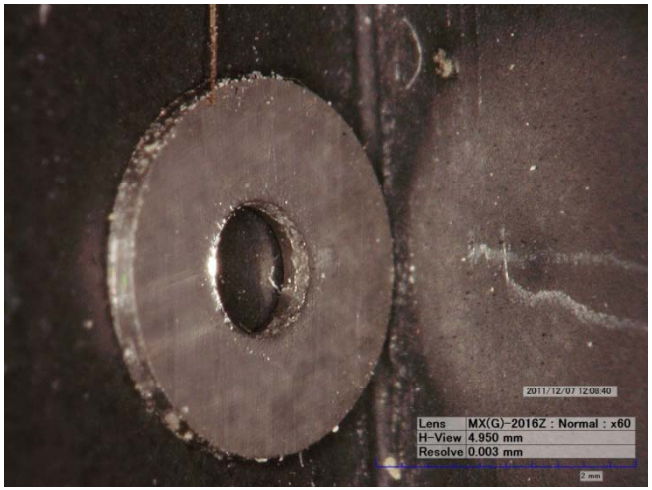
Optical Images of Sample # 3 (High Radiation Ring)

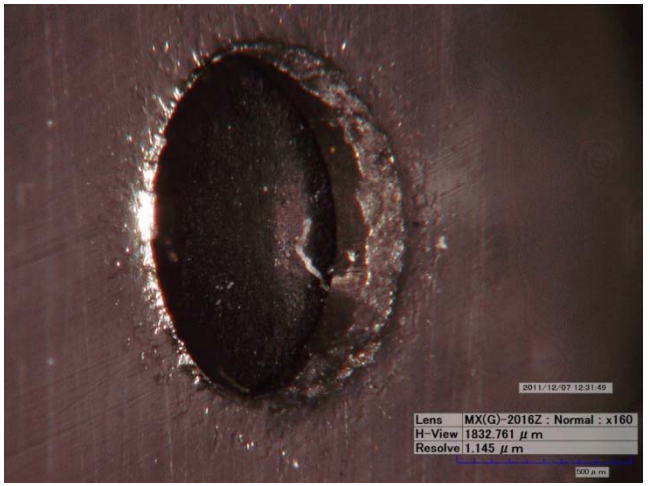


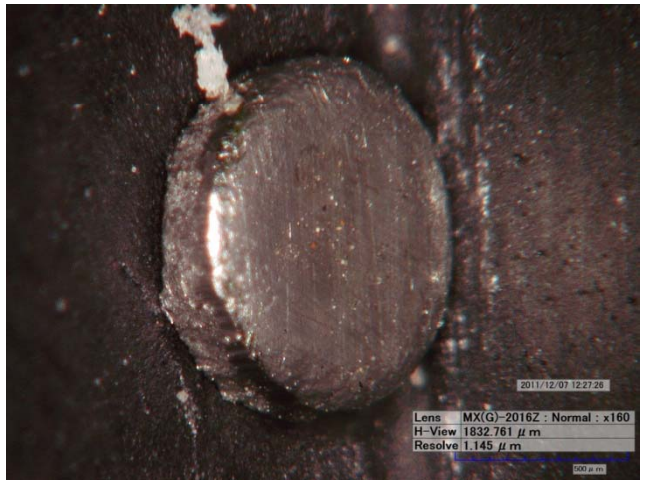


Optical Images of Sample # 8 (High Radiation Ring)





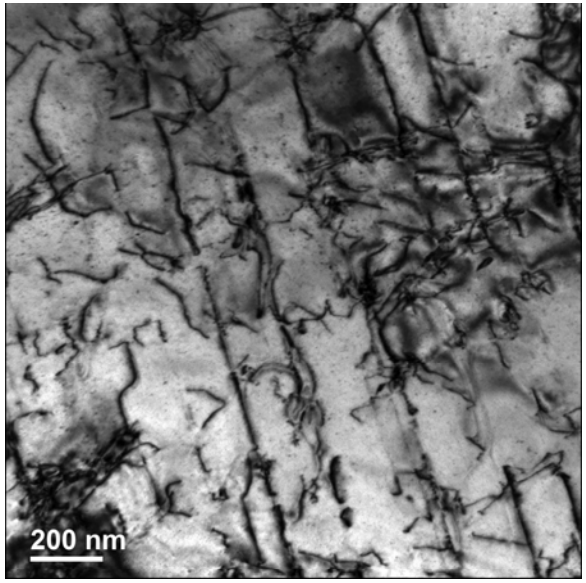


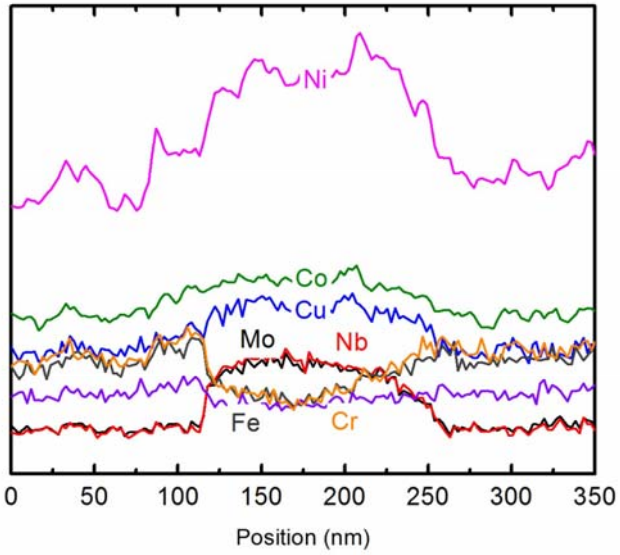


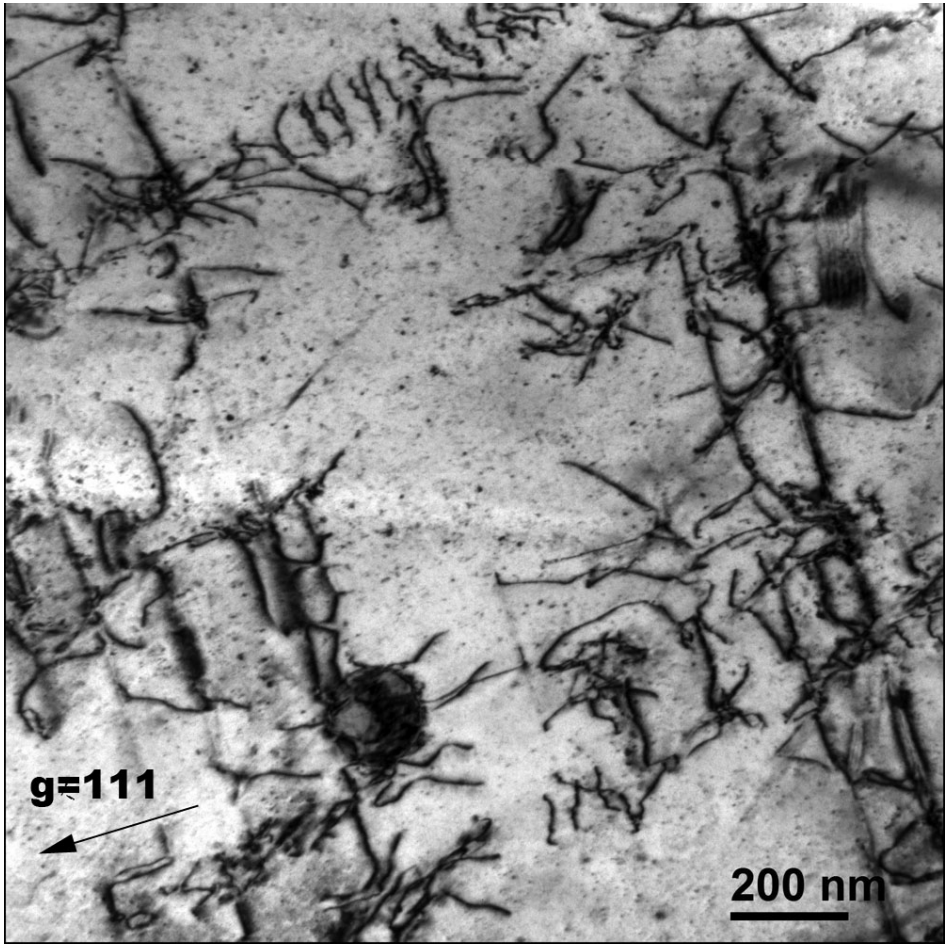
Preliminary Shear Punch Test Summary

- All samples display ductility in both yield vs UTS and optically.
- Samples taken in outer ring and outside collimator have a higher yield and UTS than control or high radiation dose samples.
  - Expected that they would be similar to the control samples.
- Shear Punch centers are being prepped for FIB and TEM to view radiation damage and initial condition.

Inconel 718-unirradiated

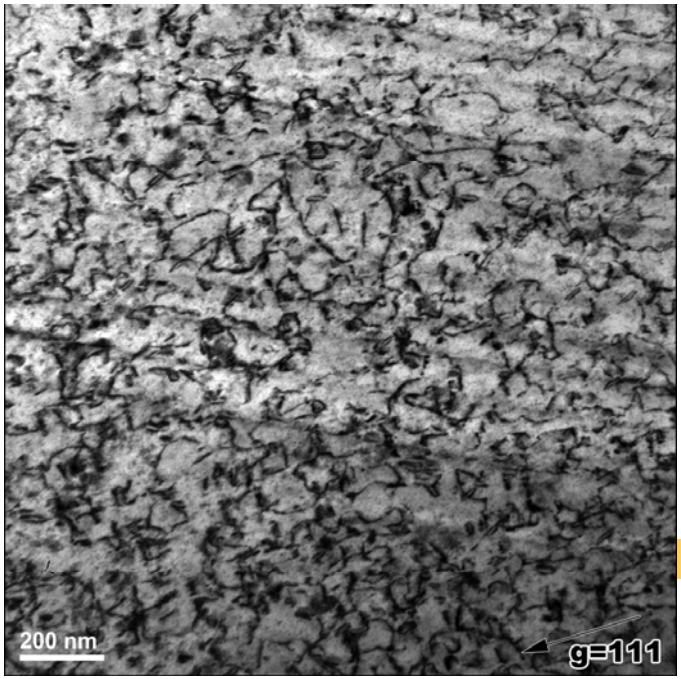


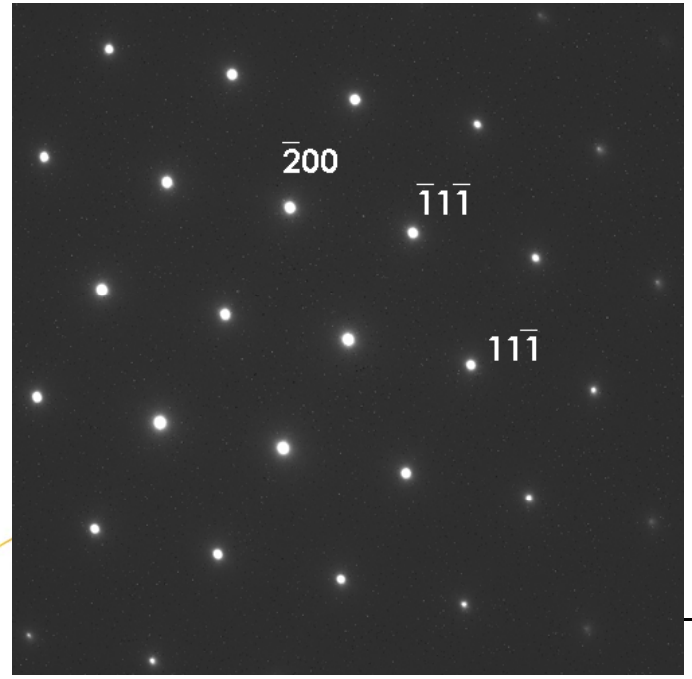


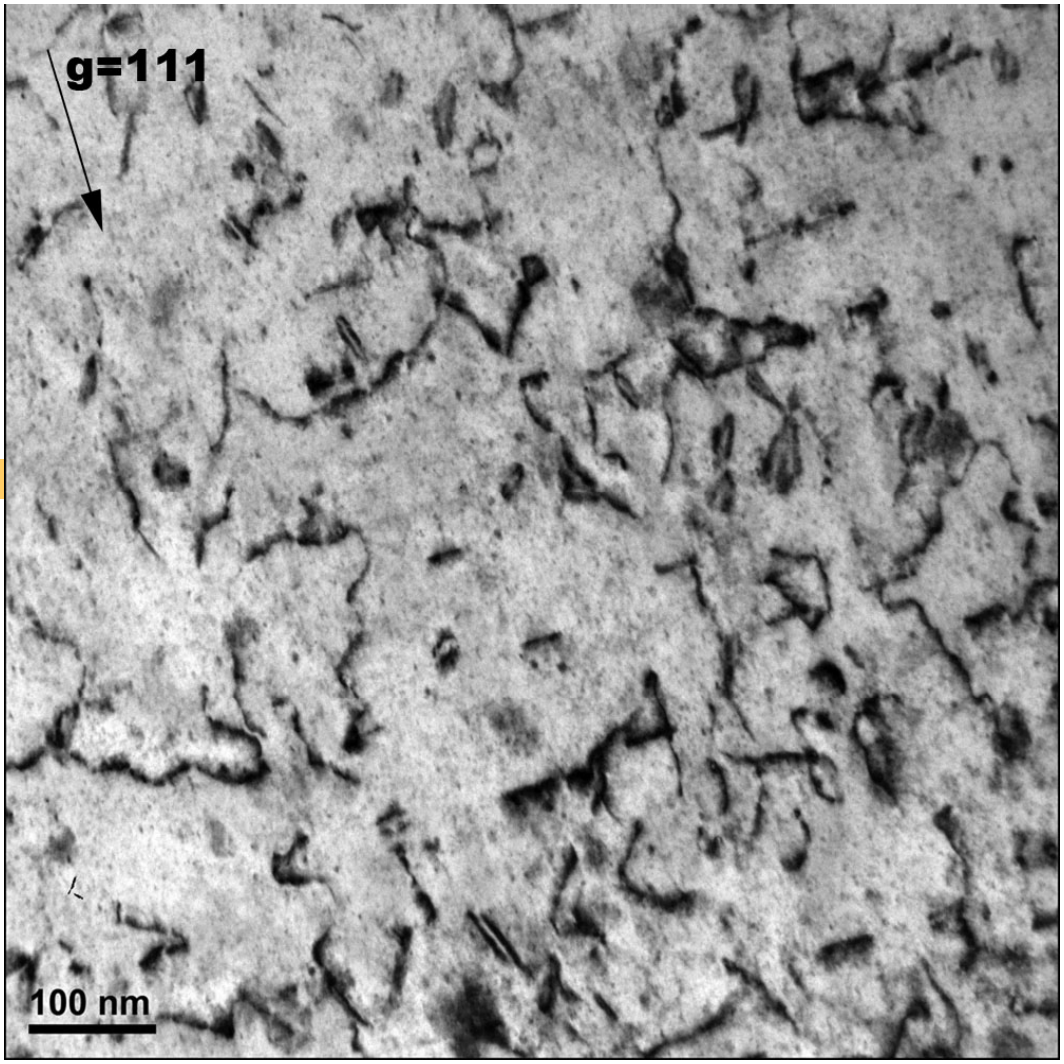


- **Bright field TEM images showing dislocations and some precipitates**

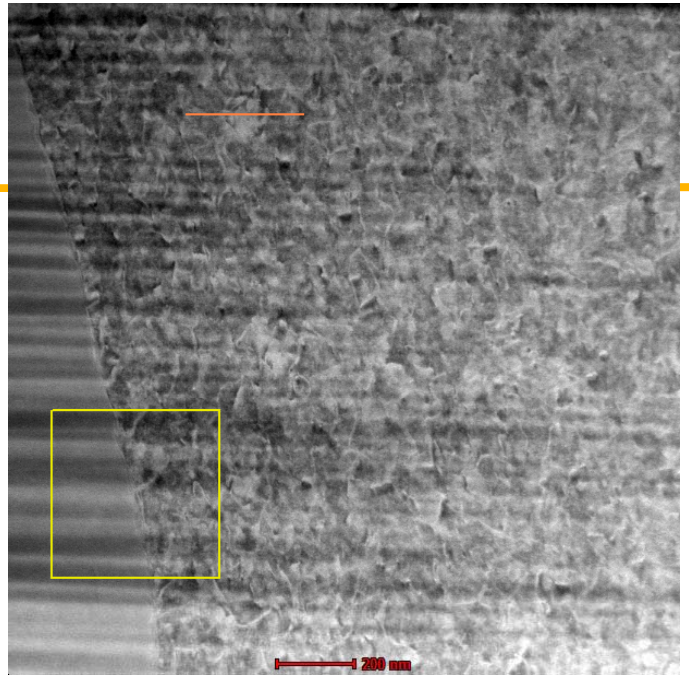
Inconel 718 #5 ~14 dpa @109°C

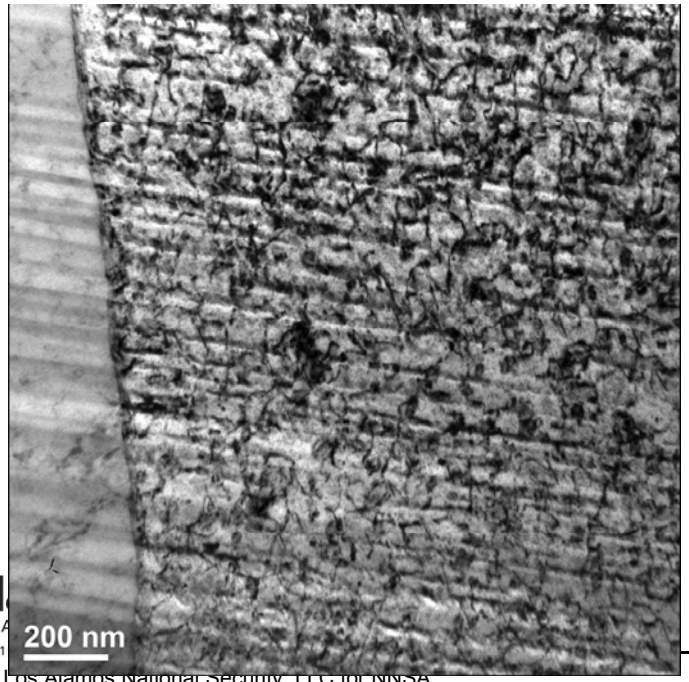


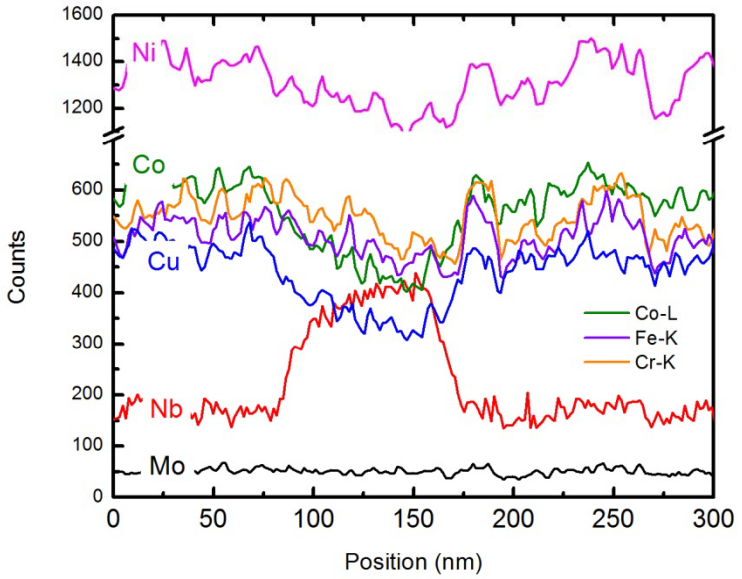


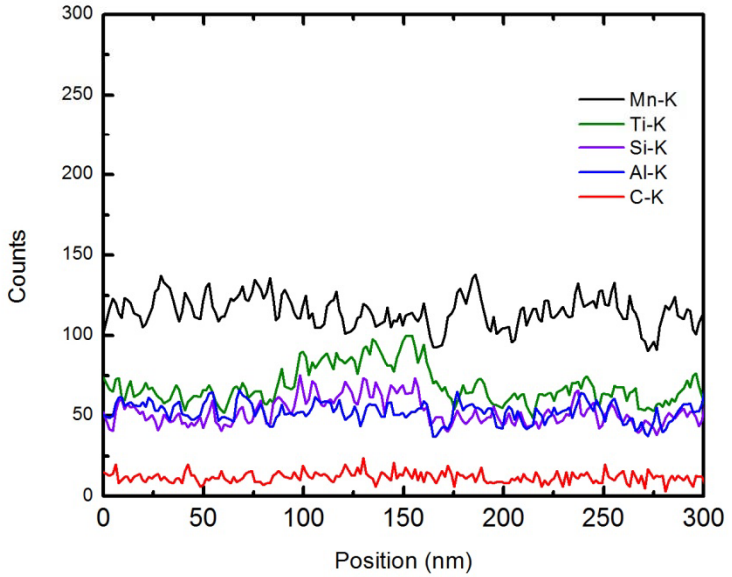


- **Bright field TEM images showing dislocations, precipitates are not detected?**



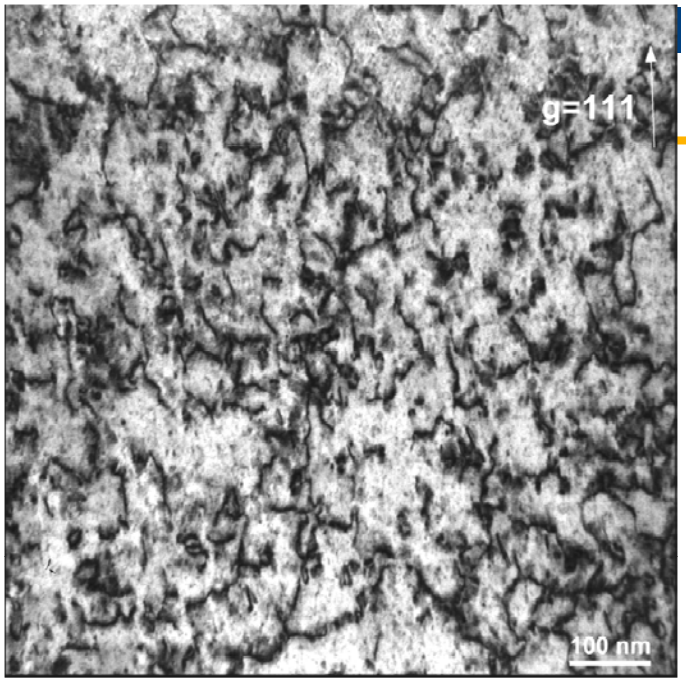


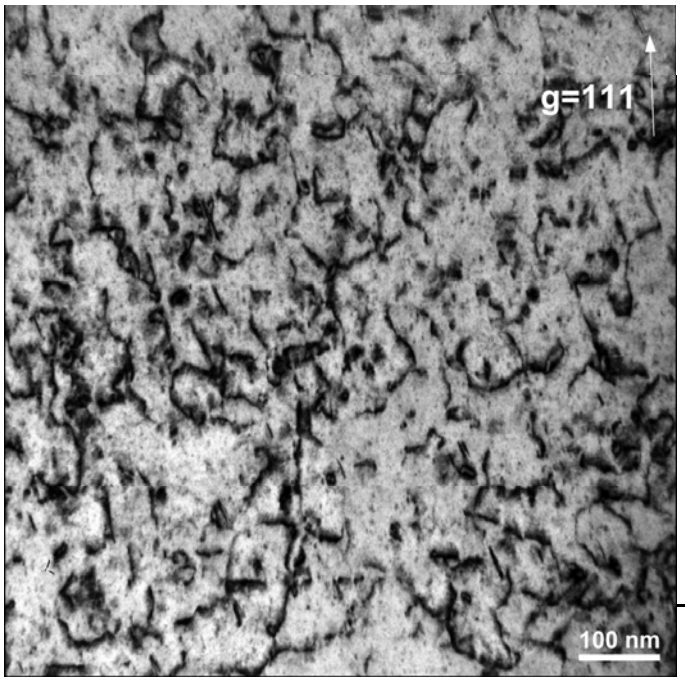


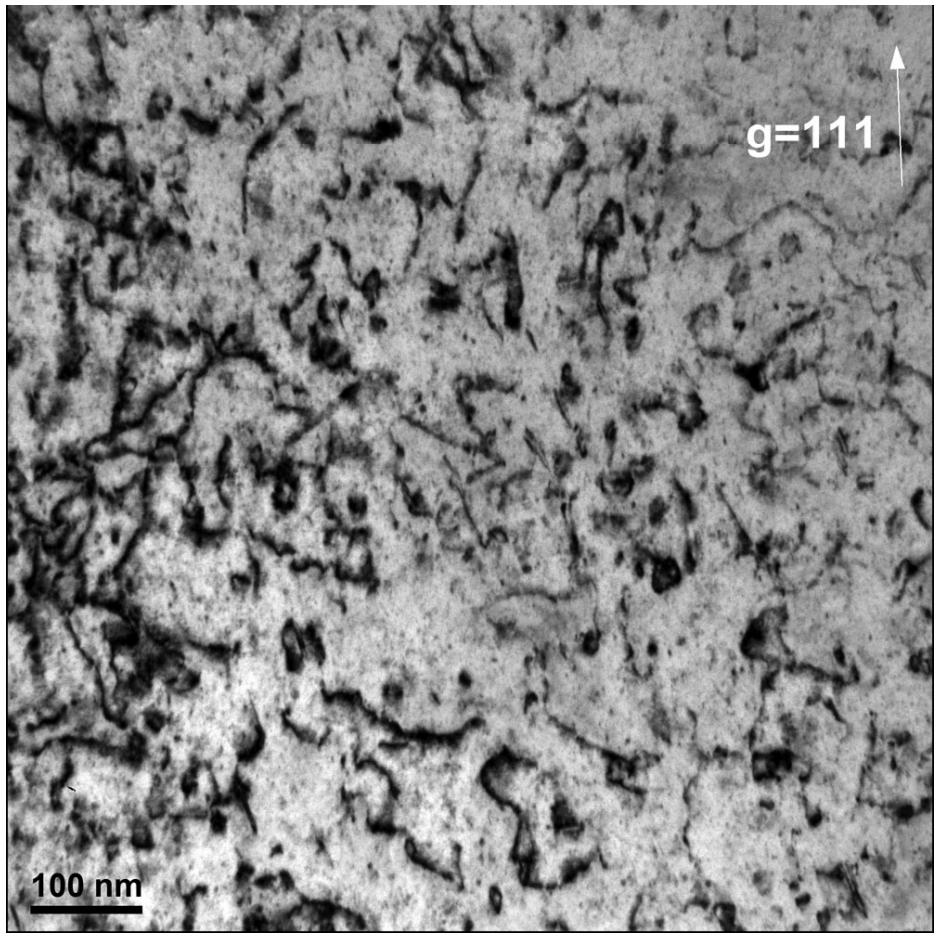


- **Dark and bright field TEM images showing smaller precipitates and dislocations.**

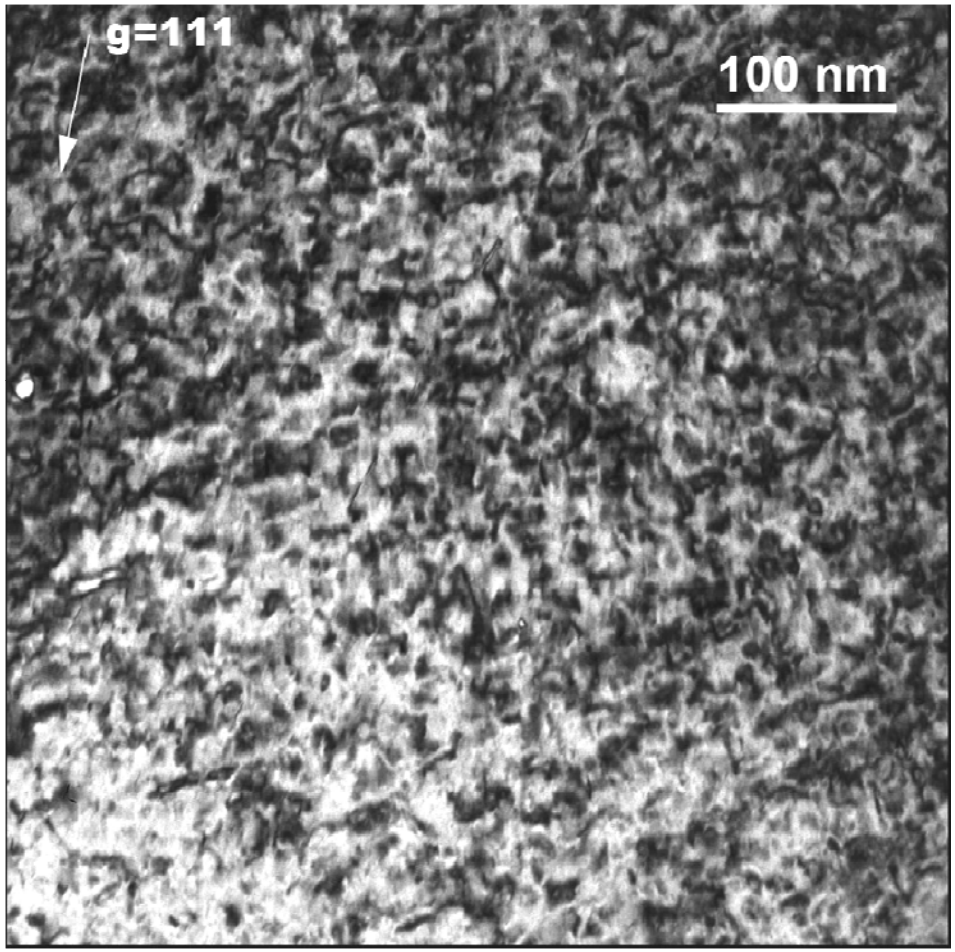
Inconel 718 #E ~11 dpa @~75°C

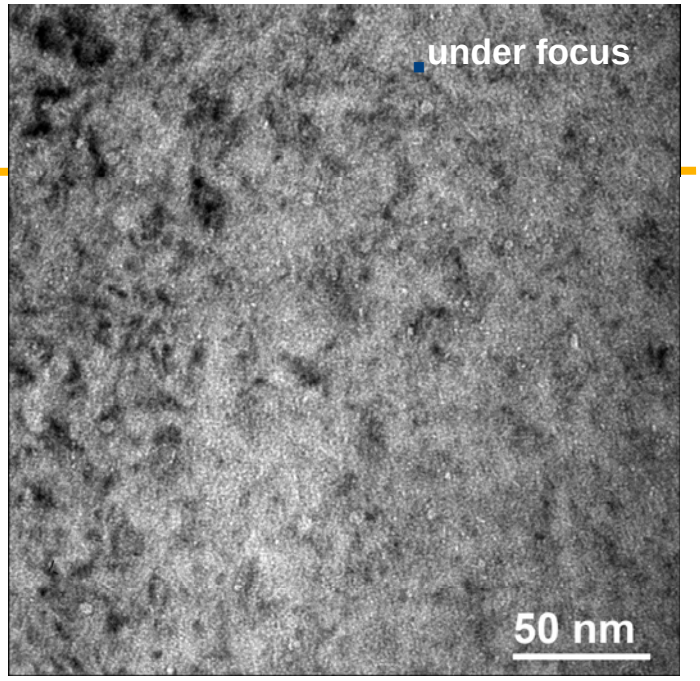


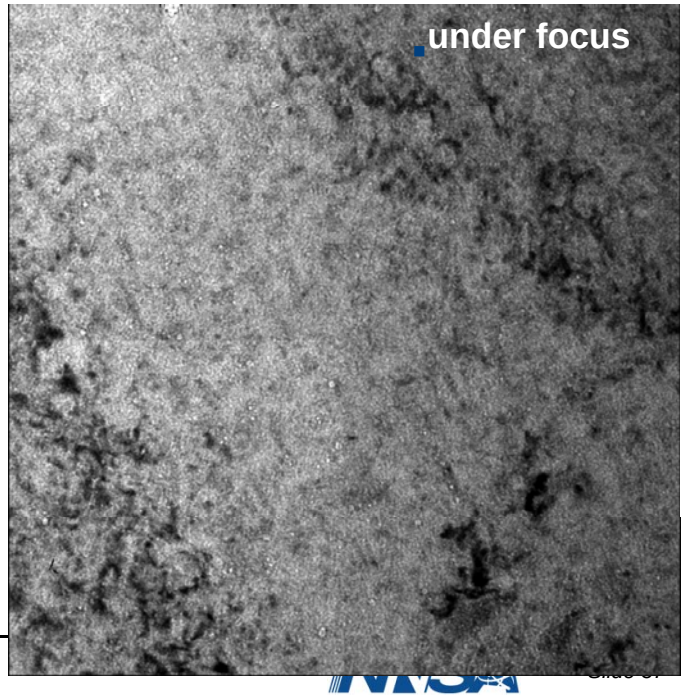




Inconel 718 #19 ~ 0.5 dpa @50°C

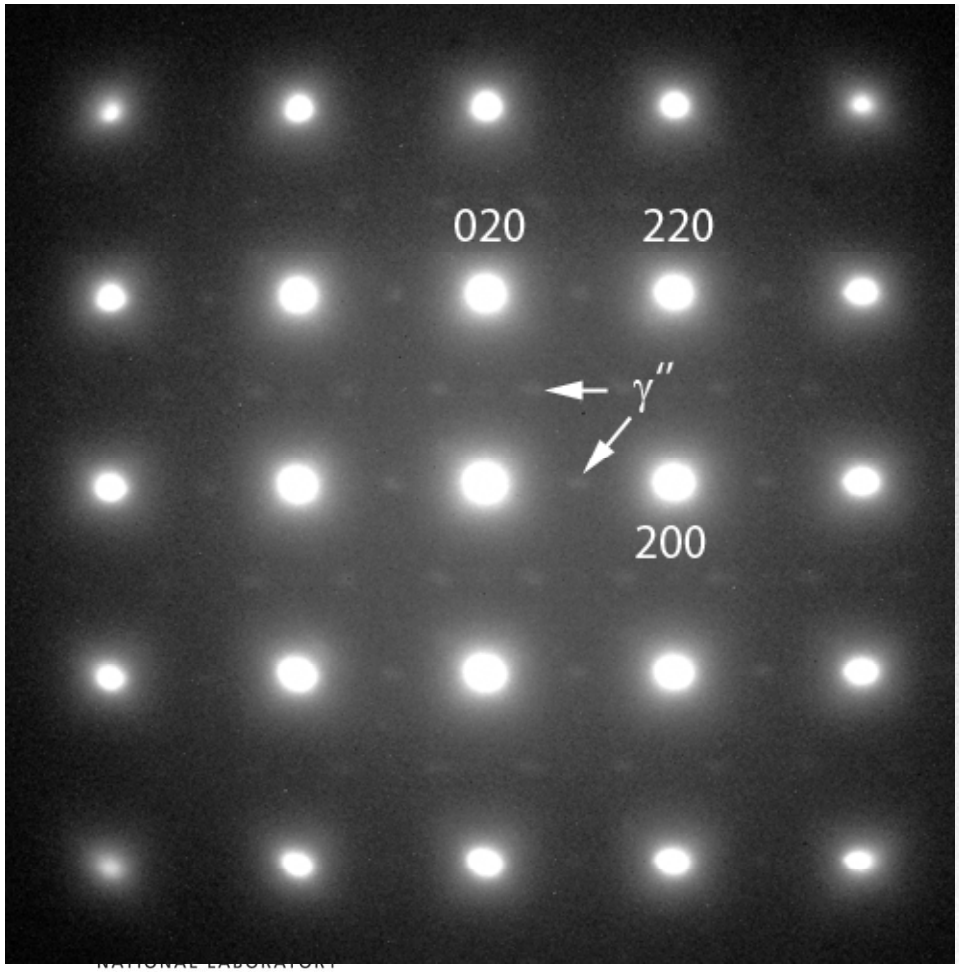


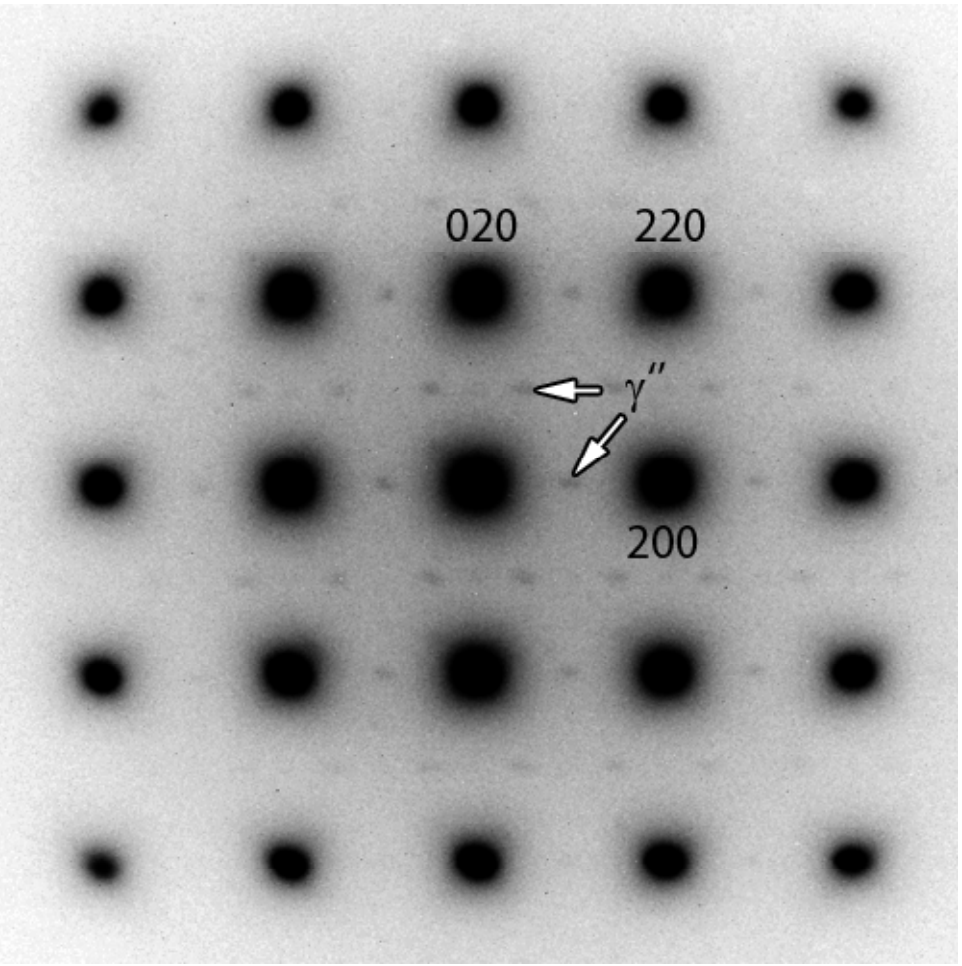




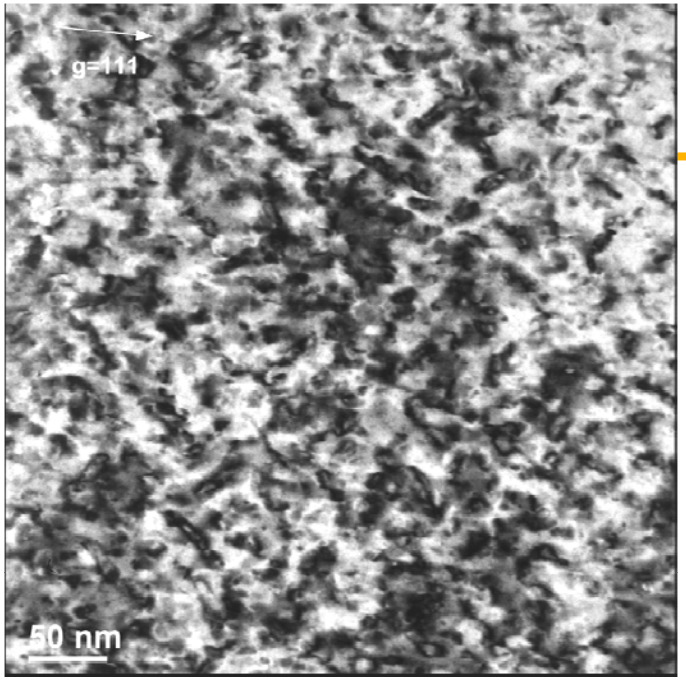
- Bright field TEM images showing dislocation loops.
- Under focus TEM images on the right are showing a high density of bubbles/voids that are on the order of 5-10nm.

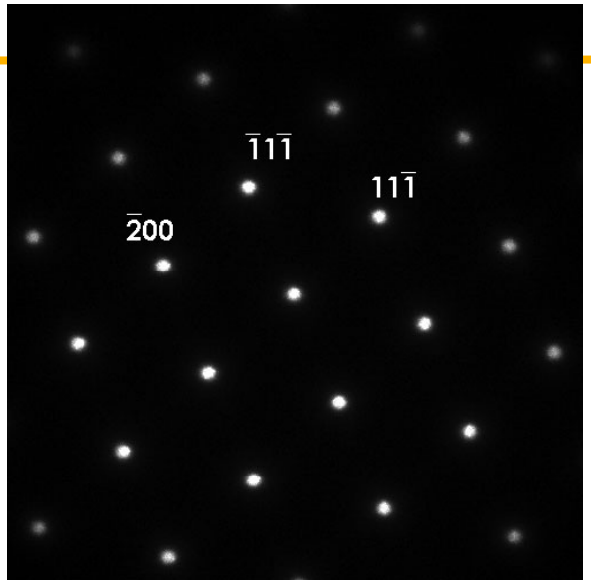
Inconel 718 #19 ~ 0.5 dpa @50°C γ“ precipitates

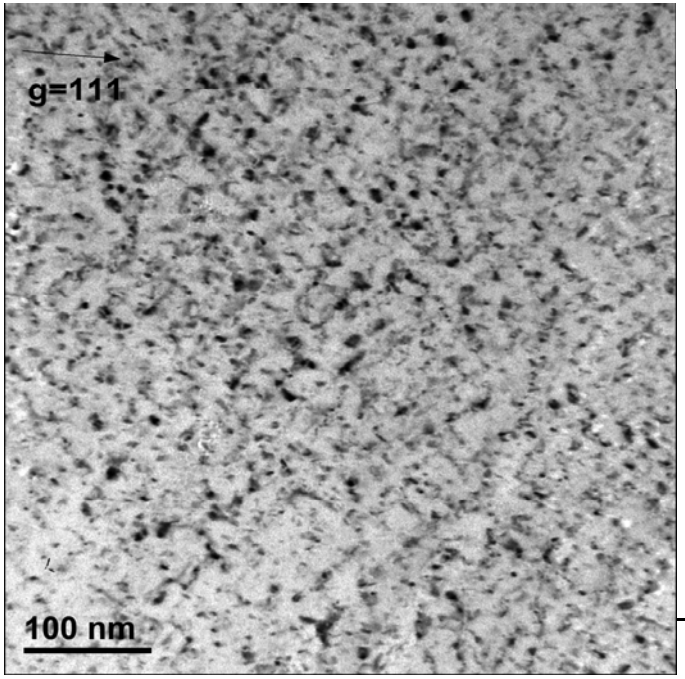


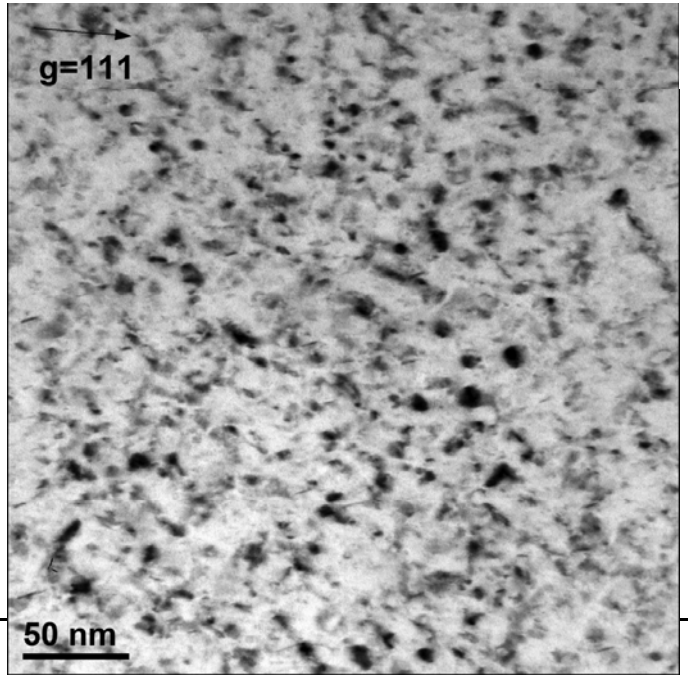


Inconel 718 #16~ 2.5 dpa @ ~40°C

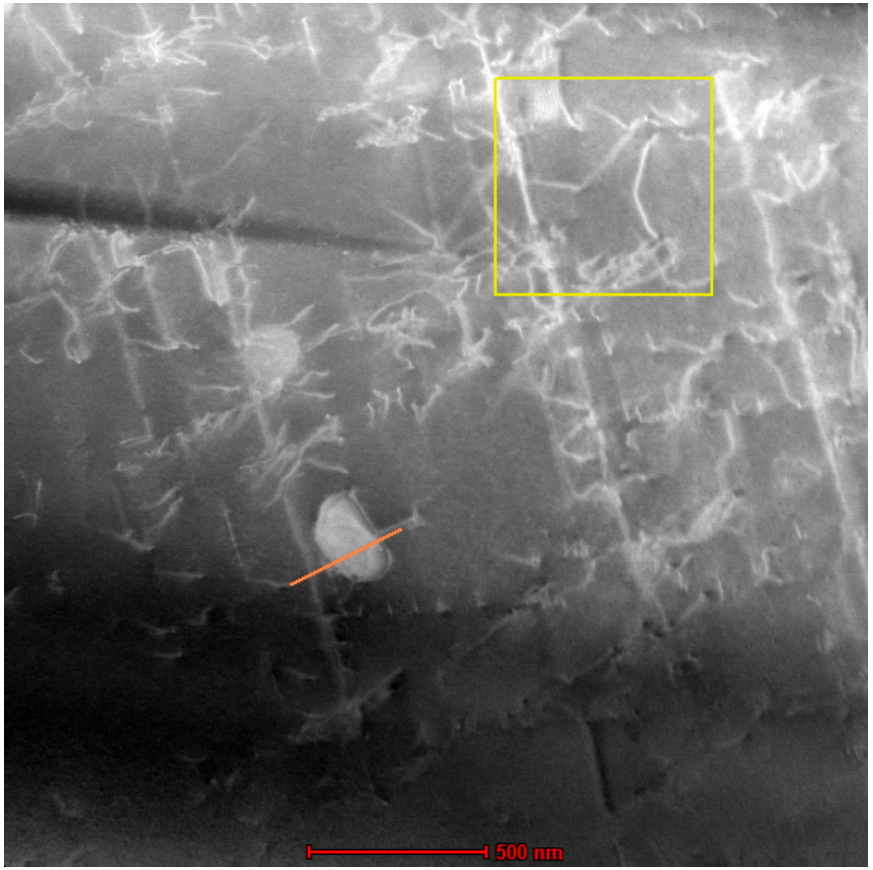


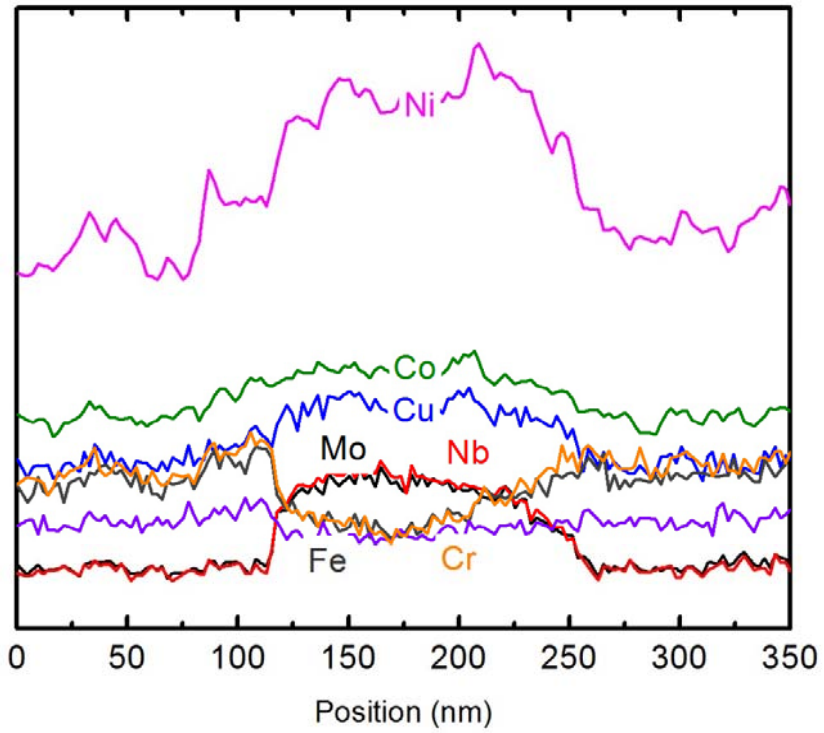


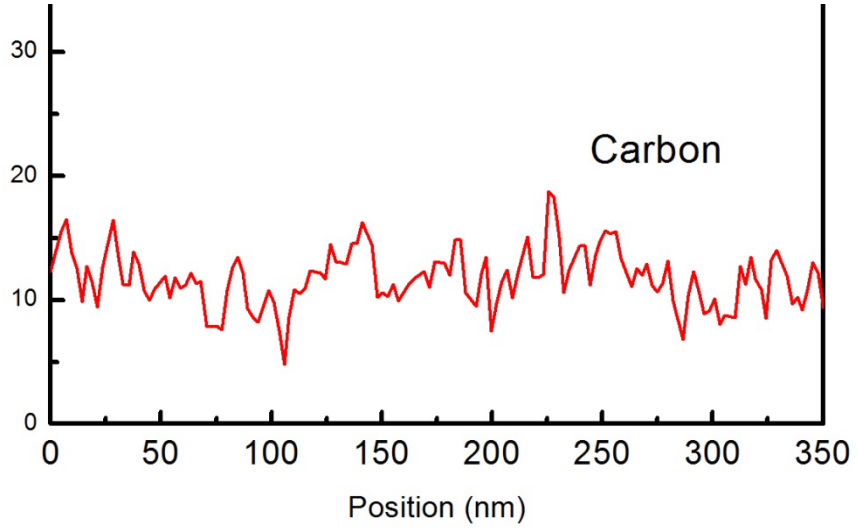




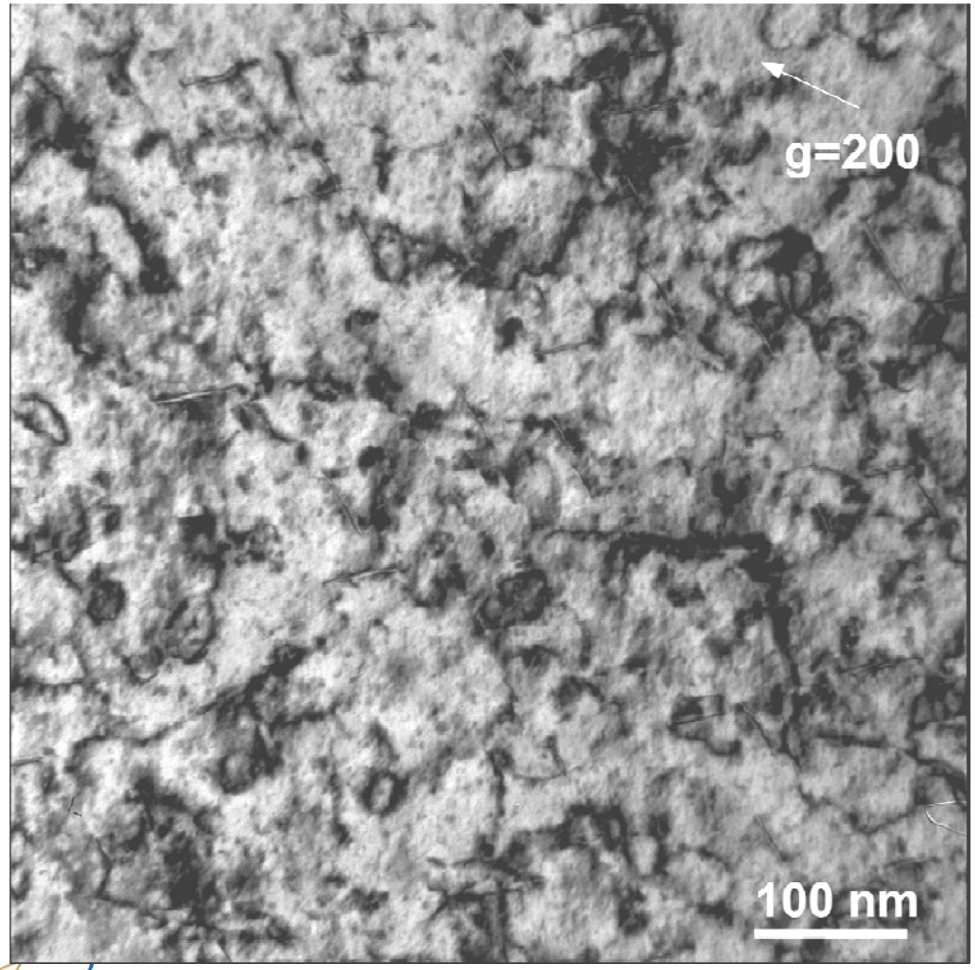
Unirradiated Inconel 718 Ni, Mo, Nb (some Co, Cu) rich precipitate







Inconel 718 #5 ~14 dpa @109°C

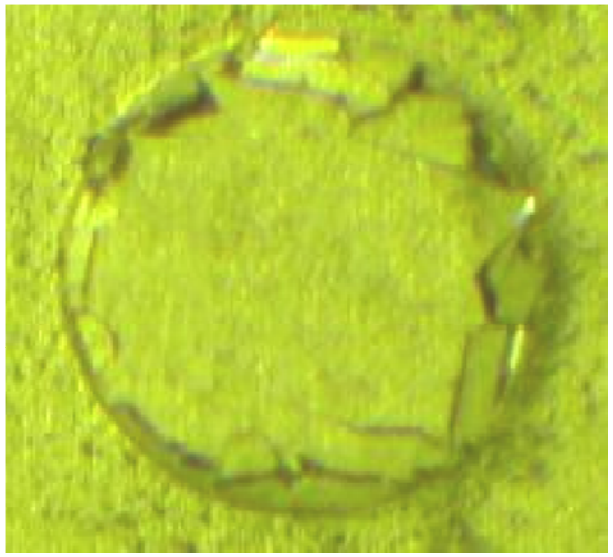


Thank You

Examples of Brittle Fracture in Shear Punch

- EP-823 tested at 25C
- irradiated to 15 dpa
- Tirr=360C

- TA-1W
- 26 dpa
- 3300appm He



- Pure Ta
- 21 dpa
- 1333appm He

Shear Punch Results